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# NASA Tech Briefs

National Aeronautics and
Space Administration

**Electronic Components and Circuits**

**Electronic Systems**

**Physical Sciences**

**Materials**

**Computer Programs**

**Mechanics**

**Machinery**

**Fabrication Technology**

**Mathematics and Information Sciences**

**Life Sciences**

# INTRODUCTION

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# Electronic Components and Circuits

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# Radiation-Tolerant CMOS Image Sensors

Several design changes to reduce radiation-induced dark current are under investigation.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Complementary metal oxide semiconductor (CMOS) integrated-circuit image sensors that are highly tolerant of high-energy radiation ("radiation hard") are undergoing development. These devices are sensitive to visible light, yet are insensitive to diverse types of highly energetic radiation, including protons at kinetic energies >1 MeV, neutrons, heavy ions, high-energy γ rays, x rays, and electrons. They can continue to function substantially as designed, even after exposure to radiation doses in excess of 10 megarad (Si).

The integrated circuits now used predominantly for visible-light image sensing are charge-coupled devices (CCDs), which are notoriously radiation-soft due to the need for repeated and accurate charge transfer. CMOS image sensors do not require charge transfer and hence are more suited for operation in radiation-rich environment. The main mechanism of degradation of a CMOS imager under radiation is the increase in dark current with total dose. The present development efforts are directed toward minimizing radiation-induced increases in dark current in CMOS image sensors.

Figure 1 is a simplified depiction of a cross section of a typical photodiode used as the photodetector in one pixel of a conventional CMOS image sensor. The photodiode is formed between the $n^+$ implant and the p substrate. The field oxide provides electrical isolation between pixels. The thickness of the field oxide is chosen to ensure that the underlying silicon cannot be inverted at any bias applied on the oxide. The transition between the field oxide and the thin oxide that covers the $n^+$ implant is denoted either the bird's beak (because of its appearance in cross section) or the LOCOS region (because it is fabricated by the local oxidation of silicon (LOCOS) process (a process of masked oxidation near the surface of the silicon substrate)).

The LOCOS region is under elevated mechanical stress, and the densities of dangling molecular bonds and interface traps in this region are greater than that at the interface between the thin oxide and the $n^+$ Si. Because the $n^+$ region is in electrical equilibrium, the interface traps above the $n^+$ region do not substantially participate in the generation of dark current. However, the LOCOS region intersects the depletion region, which is in electrical non-equilibrium.

High-energy radiation creates additional dark-current-generating centers at interfaces between silicon and silicon dioxide. In the presence of thermal excitation, these centers provide excess electrons that collectively manifest themselves as increased dark current. The generation centers are usually located in the LOCOS region because of the concentrations of stress and electric field there. Hence, a major part of the effort to reduce radiation-induced dark

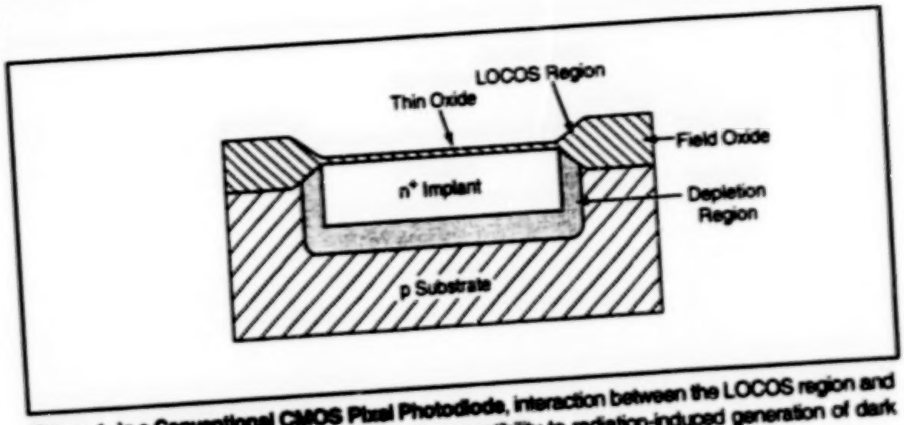


**Figure 1. In a Conventional CMOS Pixel Photodiode, interaction between the LOCOS region and the depletion region is the primary source of susceptibility to radiation-induced generation of dark current.**

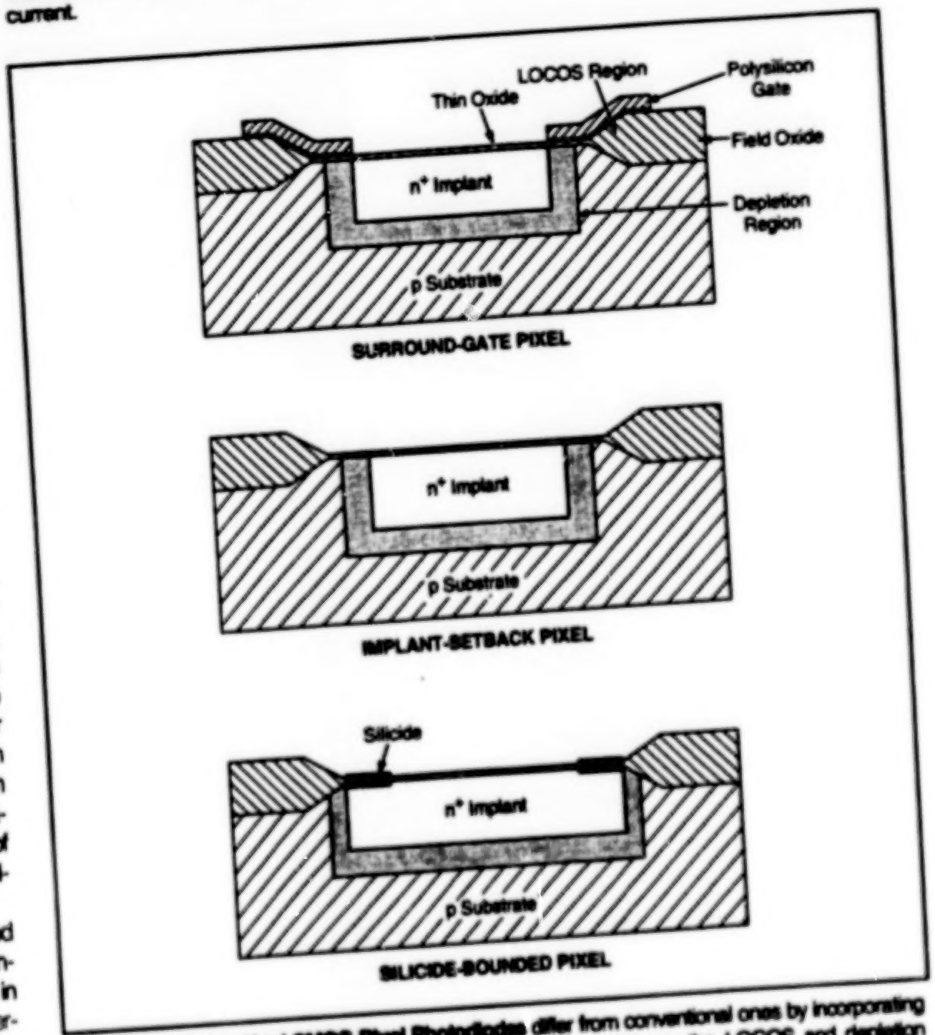


**Figure 2. Radiation-Hard CMOS Pixel Photodiodes differ from conventional ones by incorporating features that suppress the deleterious effects of interaction between the LOCOS and depletion regions.**

current has been focused on the LOCOS region.

Another part of the effort involves a radiation-hard CMOS design with superior immunity against latch-up, minimal shift of threshold voltage per unit dose of ionizing radiation, and increased stability against electric-field inversion. A third major part of the effort involves a circuit design that provides for source-follower bias field-effect transistors (FETs) arranged in a current-mirror configuration. Current-mirror-based biasing schemes are intended to provide constant bias currents, irrespective of operating temperatures and radiation doses.

Figure 2 depicts cross sections of the photodiodes in three different pixel designs of radiation-tolerant CMOS image sensors that have been investigated thus far. In the surround-gate pixel, the $n^+$ implant is separated from the LOCOS region by a polycrystalline silicon (polysilicon) gate that surrounds the implant. A sufficiently negative DC potential on the polysilicon gate (relative to the p-silicon substrate) would prevent formation of a depletion region adjacent to the LOCOS region. The negative potential would hold the region around the $n^+$ implant in accumulation, thereby passivating the interface states in the LOCOS region and thereby, further, suppressing radiation-induced dark current.

In the implant-setback pixel, the edge of the $n^+$ implant is deliberately set back from the LOCOS region to prevent interaction between the LOCOS region and the depletion region around the implant. Holding the LOCOS region in electrical equilibrium is expected to reduce the generation of dark current. A threshold-adjust implant is expected to prevent the formation of a depletion region at the surface and to provide additional radiation hardness.

In the silicide-bounded pixel, a thin silicide film is formed over an annular region around the edge of the $n^+$ silicon implant. The formation of the silicide film is expected to reduce the stress in the LOCOS region, thereby reducing the probability of formation and/or activation of dark-current-generating centers in the LOCOS region.

Tests of the three designs have led to two preliminary conclusions. The first conclusion is that silicide-bound-pixel design effects a significant reduction of both pre-irradiation and radiation-induced dark current. The second conclusion is that the silicide-bound-pixel and implant-setback-pixel designs are the most promising for implementing radiation-hard CMOS image sensors.

*This work was done by Bedabrata Pain, Bruce Hancock, and Thomas Cunningham of Caltech for* **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to*

*Intellectual Property group*
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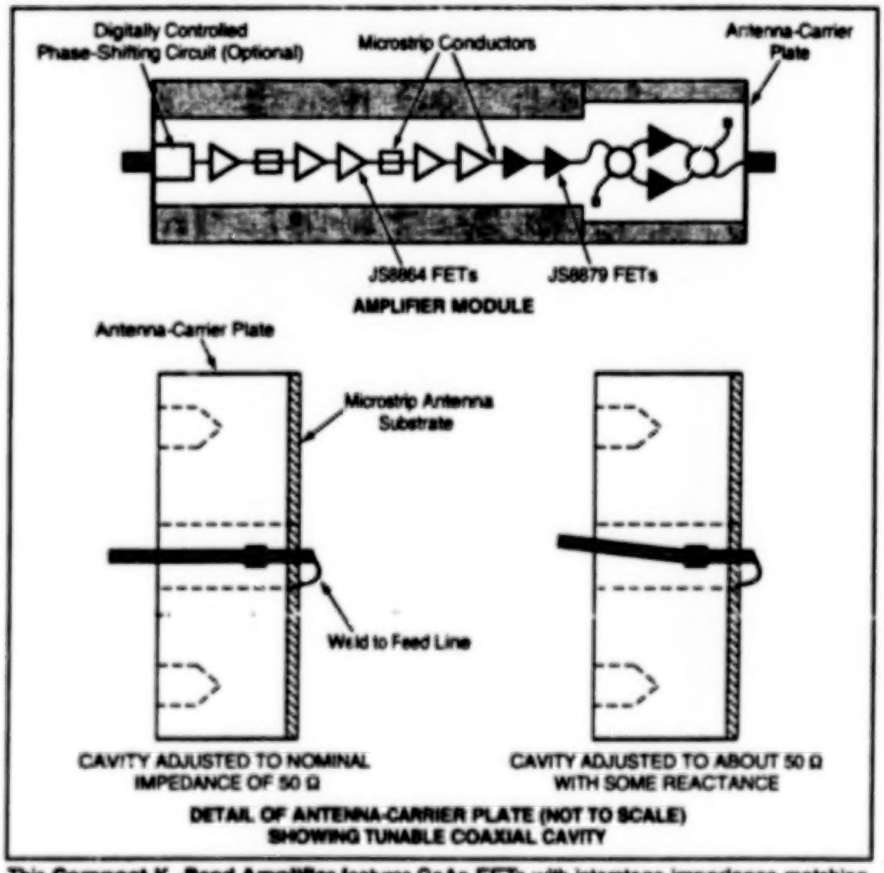
*Refer to NPO-30185, volume and number of this* NASA Tech Briefs *issue, and the page number.*

## $K_a$-Band Solid-State Power Amplifier Module

Applications could include mobile communications and phased-array antennas.

*Lyndon B. Johnson Space Center, Houston, Texas*


Digitally Controlled Phase-Shifting Circuit (Optional)
Microstrip Conductors
Antenna-Carrier Plate
JS8864 FETs
JS8879 FETs
AMPLIFIER MODULE
Antenna-Carrier Plate
Microstrip Antenna Substrate
Weld to Feed Line
CAVITY ADJUSTED TO NOMINAL IMPEDANCE OF 50 Ω
CAVITY ADJUSTED TO ABOUT 50 Ω WITH SOME REACTANCE
DETAIL OF ANTENNA-CARRIER PLATE (NOT TO SCALE) SHOWING TUNABLE COAXIAL CAVITY

**This Compact $K_a$-Band Amplifier features GaAs FETs with interstage impedance-matching microstrip conductors and a tunable coaxial cavity for matching output impedance.**

A compact $K_a$-band power amplifier has been built with GaAs field-effect transistors (FETs) and microstrip conductors on a quartz substrate. Prior to the development of this amplifier, $K_a$-band solid-state amplifiers with useful output power levels (of the order of 1 W or more) were not readily available, and it was common practice to use traveling-wave-tube amplifiers (TWTAs), which are capable of higher power levels but are also relatively bulky and expensive. TWTAs are not well suited for applications in which compactness is paramount. The present amplifier is better suited for such applications, which include phased-array antennas and mobile communication systems.

The figure illustrates the basic functional blocks of the radio-frequency part of the amplifier circuit. There are (1) five driving stages, each containing a JS8864 GaAs FET, (2) two driving stages, each containing a JS8879 GaAs FET, and (3) a power stage containing two JS8879 FETs. Impedance-matching microstrip circuits between the stages are etched in gold film on the quartz substrate. At the output end, the amplifier can be matched to a load via an antenna-carrier plate that contains a tunable coaxial cavity. The load can be a microstrip antenna mounted flush on the antenna carrier

plate, or else an external load that is reached via a coaxial connector mounted on the plate.

The amplifier provides 30.5 dB of small-signal gain over a frequency band about 760 MHz wide at a middle frequency of 29.6 GHz. The output power saturates at 28.5 dBm (≈ 0.7 W), and the onset of saturation is characterized by a 1-dB-compression output power of 25.5 dBm (≈ 0.35 W).

The development of this amplifier involved refinement of prior designs and design techniques within constraints and specifications more stringent than those governing the design of solid-state amplifiers that operate at lower frequencies. In addition to providing for a useful output power level at $K_a$ band, the design of this amplifier accommodates the planned addition of a digitally controlled radio-frequency circuit that would produce phase shifts in increments of 22.5°. Development of the amplifier was stopped before the phase-shifting circuit could be incorporated; completion of this aspect of development would be prerequisite to phased-array applications.

Some of the technological advances embodied in this amplifier may have been surpassed by other, more recent advances in solid-state $K_a$-band technology. Noteworthy examples include advances in monolithic microwave integrated circuits and high-electron-mobility transistors. Nevertheless, the present amplifier can serve as a prototype for design alternatives with commercial potential.

*This work was done by Patrick Fink of* **Johnson Space Center** *and Roland Shaw, David Kilpatrick, and Sheryl Andrews of Shason Microwave Corp. Further information is contained in a TSP [see page 1].*
*MSC-22450*

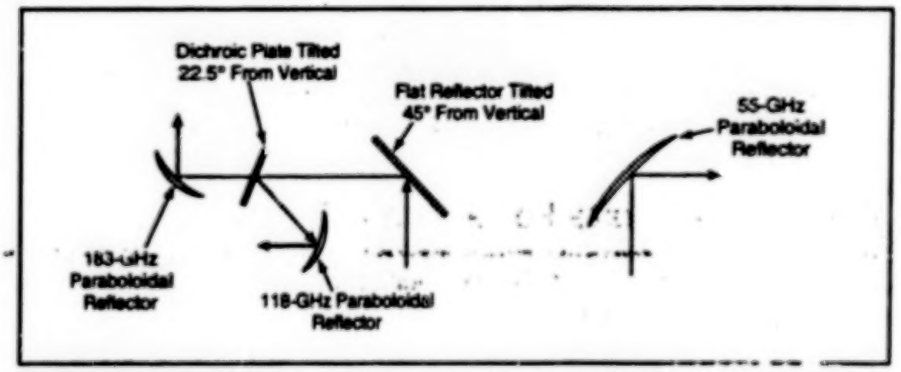
## Low-Sidelobe Microwave Reflector Antennas and Dichroic Plate

This antenna system is designed for simultaneous reception at three frequencies.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

The figure depicts the basic geometric features of an antenna system designed to be part of a miniature atmosphere-sounding passive microwave radiometer to be flown at high altitude aboard a remotely piloted aircraft. The system includes (1) a scanning flat reflector; (2) a dichroic plate; and (3) three low-sidelobe, offset-paraboloidal reflector antennas for reception in three frequency bands that include, and are denoted by, nominal frequencies of 55, 118, and 183 GHz, respectively.

In operation, the antennas are aimed downward toward the Earth. The 55-GHz reflector receives input radiation directly, while input radiation is directed to the 118- and 183-GHz antennas via the scanning flat reflector and the dichroic plate. The dichroic plate [also known as a frequency-selective surface (FSS)] is a plate that contains a hexagonal array of subwavelength-diameter holes with dimensions chosen precisely so that at an angle of incidence of 22.5° the plate transmits most of 183-GHz radiation while reflecting most of the 118-GHz radiation. The paraboloidal main reflector in each antenna concentrates the incident radiation into a corrugated feed horn, followed by a circular-to-rectangular transition, followed by a rectangular waveguide that couples the radiation into a receiver operating in the designated frequency band.


Dichroic Plate Tilted 22.5° From Vertical
Flat Reflector Tilted 45° From Vertical
55-GHz Paraboloidal Reflector
183-GHz Paraboloidal Reflector
118-GHz Paraboloidal Reflector

**The Basic Geometry of the Antenna System is shown here in simplified form for the sake of clarity.**

The feed horns were analyzed and designed by use of a full-wave mode-matching technique. The paraboloidal reflectors were analyzed and designed by use of physical-optics theory. The directional radiation patterns of the reflectors were computed by use of the near-field patterns of the feed horns. The analysis and design of the dichroic plate for the instant case of oblique incidence was based on the method of moments in conjunction with Floquet harmonics. The calculations for analysis and design were performed by use of computer programs developed at NASA's Jet Propulsion Laboratory and elsewhere for the analysis of reflector systems, corrugated horns, waveguide junctions, and frequency-selective surfaces.

*This work was done by Vahraz Jamnejad and Abraham Riley of Caltech for* **NASA's Jet Propulsion Laboratory.** *Further information is contained in a TSP [see page 1].*
*NPO-21157*

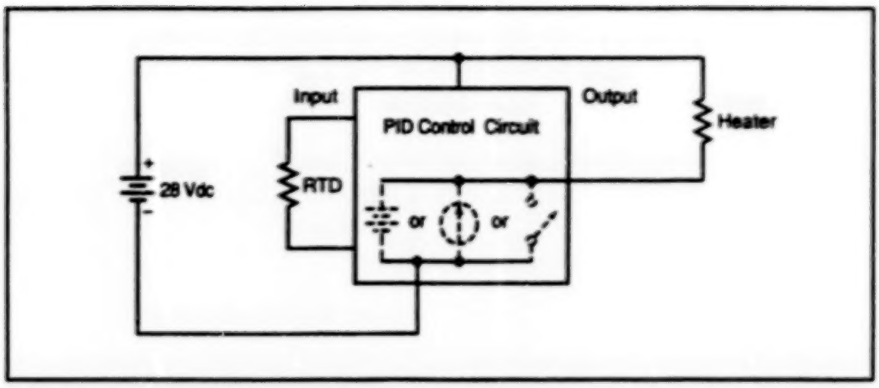
## Miniature Proportional Temperature Controllers

These would be smaller and lighter than are their commercial predecessors.

*Goddard Space Flight Center, Greenbelt, Maryland*

Miniature proportional + integral + derivative (PID) temperature controllers that would be implemented as hybrid microcircuits have been proposed to satisfy special requirements to minimize size and mass and to maintain γ-ray-detector modules at temperatures of 10±0.5 °C. These temperature controllers would be significantly smaller and less massive than are commercial PID temperature controllers, and would control temperatures more accurately than do commercial hybrid solid-state on/off-switching thermostats.

The basic idea is to sense the temperature of a module and to regulate the electric power supplied to a film heater that is bonded to the module. The major drawback of on/off switching of heater power is that it




**A Miniature PID Temperature Controller** would generate an output in the form of (1) a proportional current or proportional voltage supplied to a heater, or (2) switching of a solid-state relay for on/off control of the heater.

causes the temperature to oscillate about the set-point temperature and can give rise to significant overshoot during warmup or load changes. In the intended application, the oscillations and overshoots, as well as the temperature gradients that occur when heater power is on, make it impossible to satisfy the requirement to keep the temperature within ±0.5 C° of the set point.

A controller as proposed would supply full power to a heater until the temperature entered a specified proportional-control band that would contain the set point. The controller would then reduce the heater power gradually until the temperature became stabilized at the set point. The advantage of the PID control characteristic is that it would prevent overshoot and compensate for droop, thereby increasing the accuracy of temperature control.

The controller would have dimensions of about 0.25 by 1 by 1.5 in. (about 0.6 by 2.5 by 3.8 cm). Its mass would be about 0.5 oz (about 14 g). The figure is a simplified schematic diagram of the controller in relation to the temperature sensor and the heater. The temperature sensor would be a platinum resistance temperature detector (RTD) or epoxy-encapsulated thermistor, which could be either separate from the controller or laminated inside the body of the controller. Hybrid microcircuits inside the body would generate the PID response.

Due to the use of hybrid microcircuits, each controller could consist of multiple temperature control units. This reduces the number of temperature controllers required significantly. Also, the temperature set point of the controller could be changed in flight by using a temperature-versus-voltage calibration curve.

*This work was done by Michael K. Choi of* **Goddard Space Flight Center.** *Further information is contained in a TSP [see page 1].*
*GSC-14315*

## Simple Phase Shifter for a Scanning-Beam Antenna

Phase is shifted by mechanically perturbing dielectric/air/conductor boundaries.

*John H. Glenn Research Center, Cleveland, Ohio*

A simple, inexpensive device has been conceived for shifting the phase of a signal in a feed line of a scanning-beam microstrip antenna in order to change the direction of the beam. Heretofore, phase shifters used for this purpose have been relatively bulky and expensive.

The phase shifter and the overall scanning antenna are made more compact than they otherwise would be by integrating the feed line and the phase shifter. The feed line in this case is a dielectric waveguide made of a ceramic that is characterized by low loss at a wavelength of the order of a millimeter. The waveguide feeds the microstrip antenna through a slot.

The design of the device exploits the fact that the phase velocity, and thus the phase, of a signal propagating along the ceramic waveguide, can be varied by perturbing dielectric/air/conductor boundaries. In particular, the variation in phase and thus the scanning ability of the beam is effected by rotating a cam on top of the ceramic waveguide. The phase varies with the gap between the ceramic waveguide and the cam.

The development of this device is at the prototype stage. The one major source of difficulty in fabrication and use is that the waveguide/cam gap is less than a tenth of a millimeter and must be controlled accurately.

*This work was done by XiaoDong Wu, Robert Knox, Kenneth Gilliam, and Dawei Li of Epsilon Lambda Electronics Corp. for* **Glenn Research Center.**

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16912.*

## High-Capacity Nickel-Hydrogen Cells

These cells retain capacity and integrity under severe conditions.

*John H. Glenn Research Center, Cleveland, Ohio*

Nickel-hydrogen electrochemical cells with capacities of 350 ampere-hours have been developed. These cells are intended primarily for use in government and commercial satellites; they have been fully qualified to satisfy performance requirements for operation in geosynchronous satellites for as long as 15 years. They may also prove useful in terrestrial applications in which there are requirements for long-life, lightweight, high-capacity cells that retain capacity over a wide temperature range and retain integrity when subjected to severe acceleration.

Each cell has a diameter of 5.5 in. (≈14 cm). Notable features of the cell design and construction include the following:

- Electrochemically impregnated, sintered nickel positive electrodes;
- Single-layer zirconium oxide cloth separators;
- Platinum-catalyzed hydrogen electrodes;

- High-current cell terminals; and
- A lightweight nickel-alloy pressure vessel.

In a test, a pressure vessel of the type used in these cells withstood a pressure of 2,100 psig (gauge pressure ≈14.5 MPa) without bursting. In another test, a cell exhibited both electrical and mechanical integrity after exposure to a sine burst of acceleration with an amplitude of 50 times normal Earth gravitation. In still another test, a cell exhibited charge/discharge capacities above those of acceptance requirements at temperatures from –22 to +42 °C.

*This work was done by Robert K. Taenaka, Allen R. Powers, W. Rex Oswald, and Joel A. Schwartz of Hughes Space & Communications Co. for* **Glenn Research Center**. *Further information is contained in a TSP [see page 1].*

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16867.*

# Books and Reports

## Skutterudite Thermoelectric Unicouples for Generating Power

A report presents some results of continuing efforts to develop advanced thermoelectric devices and, more particularly, thermoelectric unicouples for generating electric power from diverse thermal sources, including automotive exhausts and other waste-heat sources. The basic principles of operation and design of these devices were described in "Highly Efficient Thermoelectric Unicouples" (NPO-20872), *NASA Tech Briefs*, Vol. 24, No. 10 (October 2000), page 42. The report reiterates the basic principles and then goes on to describe two thermoelectric-unicouple designs, the first of which is theoretically optimal and similar to that of a segmented thermoelectric unicouple described in the cited previous article. The second design — a variant of the first design — is that of an experimental unicouple that was made from skutterudite (only) thermoelectric materials: $CeFe_4Sb_{12}$-based (p-type) and $CoSb_3$-based (n-type) alloys. The report describes the fabrication and the thermal and electrical tests of the experimental unicouple. Among the reported test results are a thermal-to-electrical energy-conversion efficiency of as much as 9.8 percent during operation at hot- and cold-side temperatures of 863 and 363 K, respectively. The report projects that, in the future, more nearly optimal designs could yield efficiencies as large as 15 percent.

*This work was done by Thierry Caillat, Jeff Snyder, Andrew Zoltan, and Leslie Zoltan of Caltech for* **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Skutterudite Thermoelectric Unicouples for Power Applications," see TSP's [page 1].*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to*

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*JPL*
*Mail Stop 202-233*
*4800 Oak Grove Drive*
*Pasadena, CA 91109*
*(818) 354-2240*

*Refer to NPO-30128, volume and number of this NASA Tech Briefs issue, and the page number.*

## ASIC for Controlling a Power-Switching MOSFET

A report describes an application-specific integrated circuit (ASIC) for controlling a power-switching metal oxide semiconductor field-effect transistor (MOSFET) in a spacecraft power-supply system. Denoted an SCA (for switch-control ASIC), this ASIC is designed to be radiation-hard and to function over a wide temperature range during a long operational lifetime. The power-switching requirements for most spacecraft include a significant amount of control for protection against load faults, to effect distribution of power, and to switch power quickly and safely for such purposes as igniting pyrotechnic devices and changing valve positions. The design of the SCA enables a single chip set to perform all of the digital, analog, and power functions needed to satisfy these and other power-control requirements for a given spacecraft. The SCA design enables a factor-of-two increase in packaging density and a reduction in power consumption, relative to state-of-the-art power-switching circuitry.

*This work was done by Barbara Lam, Clint Kwa, David Zhu, Gene Wester, Gregory Carr, John Bennett, Lauro Franco, David Hogue, Pete Skelly, and Russ Haskal of Caltech for* **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Switch Control ASIC," see TSP's [page 1].*
*NPO-30280*

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# Electronic Systems

## Books and Reports

15 Cooperative Communication by Low-Power Radio Transmitters

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# Books and Reports

## Cooperative Communication by Low-Power Radio Transmitters

A report proposes a method of cooperative modulation between (1) low-power radio transceivers associated with sensors geographically dispersed on a remote planet for relaying information between the sensors and an Earth station. The method, denoted node selection on orthogonal channels (NSOC), would make it unnecessary to include an additional, intermediate-power base station on the planet to effect long-distance communication with the orbiting transceiver. At much lower power demand than that needed for communication with the orbiting transceiver, the sensor stations (regarded as nodes) would communicate among themselves, sharing the information to be uplinked and synchronizing themselves for cooperative modulation with the orbiting transceiver. Once the information has been shared locally, all nodes would cooperatively transmit the message in the following sense: Based on the shared information, a group of bits is used to select a node to transmit an additional bit over its unique orthogonal channel. Thus, information is conveyed in the transmitted bit as well as the selected transmission channel. The net effect would be to afford a gain in energy efficiency over that of an equivalent single transmitter.

*This work was done by Kevin Quirk, Meera Srinivasan, and Jonathan Agre of Caltech for* **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Cooperative Communication Using Node Selection, Orthogonal Channels," see TSP's [page 1].*

*NPO-30177*

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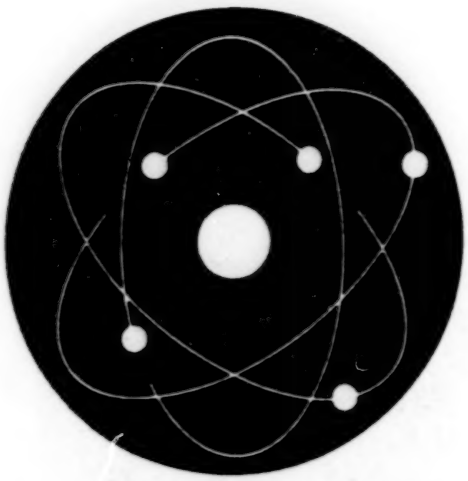

# Physical Sciences

## Hardware, Techniques, and Processes


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20 Micromachined Emitter/Bolometer Structures for Infrared Gas Sensors
21 Deployable Shell Structures With Shape-Control Actuators
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22 Uplink/Downlink Spacecraft Radio Occultation Measurements

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# Development of Sensors for Detecting Leaks of $O_2$ and $H_2$

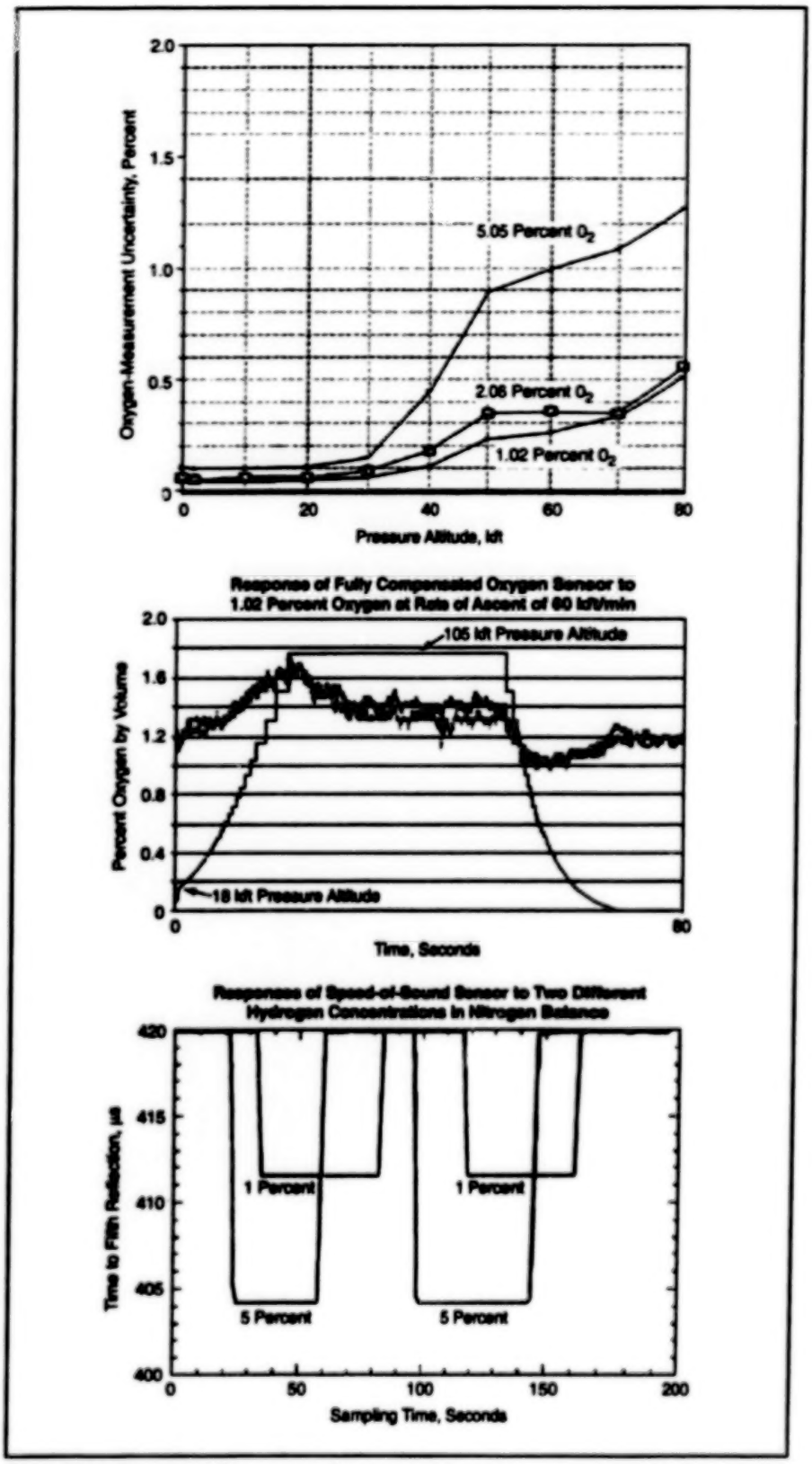
Both commercial and noncommercial sensors show promise.

*Dryden Flight Research Center, Edwards, California*

The Propulsion group at Dryden Flight Research Center is performing analyses of the effectiveness of chemical-species sensors for detecting and assessing leakage. The group is also studying relationships between (1) rates at which high-energy species leak from the propellant-feed systems of advanced aircraft and spacecraft and (2) the rates of leakage of inert species substituted for the high-energy species in the same systems. Several commercial sensors and a prototype noncommercial sensor have been and continue to be subjected to tests of their ability to detect their respective chemical species accurately and quickly. Analysis of the data from these tests is expected to determine whether it is possible to develop instruments capable of detecting propellant leaks over a wide range of temperature and pressure. If suitable, the instruments can be employed in various flight experiments in which there are requirements for such leak-detection capability. Analysis of data from inert- and high-energy-propellant leak testing will help in scaling leakage from gaseous propellant feed systems without the need to use high-energy propellants during subsequent leak tests.

Commercial-off-the-shelf (COTS) oxygen sensors that were intended for automotive and medical uses have proven quite effective for monitoring oxygenated environments. Calibrations with a 1 percent oxygen gas have demonstrated uncertainty of 0.1 percent at pressure altitudes up to 50 kft (≈15 km). The top part of the figure presents results of an uncertainty analysis of one these sensors. The middle part of the figure presents results of a dynamic test in which a calibrated fully compensated (that is, pressure-and-temperature-compensated) oxygen sensor was operated at a rate of ascent of 60 kft/min (≈0.3 km/s) from 18 kft (≈5.5 km) to 105 kft(≈32 km) and found to be accurate to within 0.7 percent. The lower part of figure presents results of a test in which a prototype sensor that measures changes in the speed of sound was found to afford a capability for measuring concentrations of hydrogen mixed into nitrogen.

Calibration of the COTS and the fully compensated oxygen sensors have been finished and these sensors have been integrated into the Hyper-X vehicle (an experimental hydrogen-fueled hypersonic


Oxygen-Measurement Uncertainty, Percent
5.05 Percent $O_2$
2.06 Percent $O_2$
1.02 Percent $O_2$
Pressure Altitude, kft
Response of Fully Compensated Oxygen Sensor to 1.02 Percent Oxygen at Rate of Ascent of 60 kft/min
105 kft Pressure Altitude
18 kft Pressure Altitude
Percent Oxygen by Volume
Time, Seconds
Response of Speed-of-Sound Sensor to Two Different Hydrogen Concentrations in Nitrogen Balance
1 Percent
1 Percent
5 Percent
5 Percent
Time to Fifth Reflection, μs
Sampling Time, Seconds

**These Plots Represent Responses** of oxygen and hydrogen sensors tested in the program described in the text.

airplane) for flight testing. Validation testing of these sensors was scheduled to begin at or about the time of reporting the information for this article. Calibration and dynamic tests of a fully compensated hydrogen sensor were also scheduled to begin about a month earlier. It was expected that if the results of the tests of the hydrogen sensor show that requirements are satisfied, then this sensor would also be integrated into the Hyper-X vehicle. Also at the time of reporting:

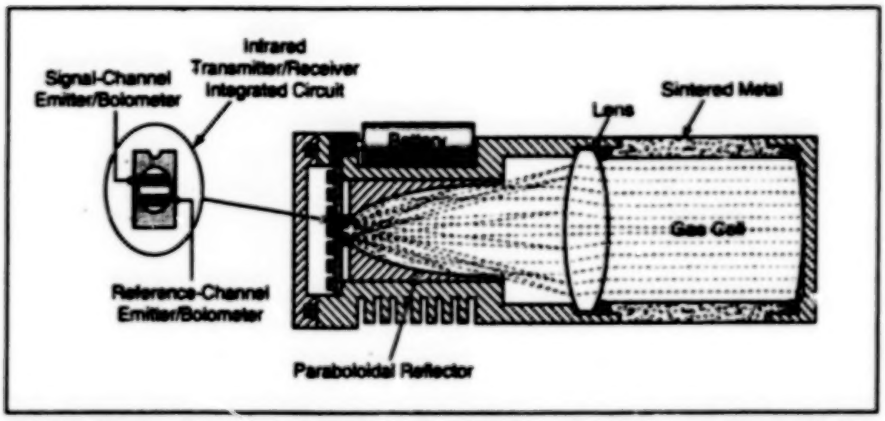
- Negotiations to procure another prototype speed-of-sound sensor for characterization and calibration were under way; and
- At the University of California at Los Angeles, there was research in progress to determine a correlation between the rates of leakage of gaseous hydrogen and gaseous helium.

*This work was done by Neal Hass of* **Dryden Flight Research Center**. *DRC-01-36*

## Micromachined Emitter/Bolometer Structures for Infrared Gas Sensors

Small, inexpensive, mass-producible gas sensors would be enabled by these novel micromachined wavelength-selective emitter/bolometers.

*NASA's Jet Propulsion Laboratory, Pasadena, California*




**This Gas Sensor, shown here at approximately actual size, will contain a wavelength-selective infrared emitter/bolometer and associated optical components. Infrared absorption in the gas of interest would affect the temperature, and thus the electrical resistance, of the emitter/bolometer.**

Infrared gas sensors that could be mass-produced at relatively low cost have been proposed for a variety of applications — for example, detecting carbon monoxide in air inside houses. A sensor of this type would include a housing into which ambient air could diffuse. The gas of interest would be detected via an infrared absorption measurement. The novel micromachined emitter/bolometer structure being developed is a heated strip of lithographically patterned, single-crystal silicon that will function as both an emitter of infrared radiation at a precise wavelength and as a bolometer. The emitted radiation would traverse a path within the sensor housing and would be reflected back along that path to the emitter/bolometer. In the presence of an infrared-absorbing gas, the amount of radiation returning to the emitter/bolometer would decrease, causing the emitter/bolometer to come to thermal equilibrium at a lower temperature than it would in the absence of such a gas. The temperature-dependent electrical resistance of the emitter/bolometer would be measured and used to infer the concentration of the infrared-absorbing gas.

In addition to the emitter/bolometer, the sensor housing would contain a paraboloidal reflector, a lens, and a mirror that would direct the infrared radiation along the desired optical path beginning and ending at the emitter/bolometer (see figure). To maximize the sensitivity and signal-to-noise ratio of the sensor, the emitter/bolometer surface would be made (as described in more detail below) to emit and absorb maximally over a narrow band of wavelengths rather than over the whole black-body spectrum. Also to maximize sensitivity, the emitter/bolometer would be in the form of a suspended single-crystal silicon resistor with a high temperature coefficient of resistance.

The development of the proposed gas sensors and, in particular, the wavelength-selective emitter/bolometer components of the sensors, would exploit advances in (1) the understanding of the interactions between electromagnetic radiation and textured solid surfaces and (2) the wafer-scale fabrication of semiconductor devices. It has been observed in prior experiments that a surface textured microscopically by ion-beam etching exhibits increased optical absorption over a defined wavelength band, and, when heated, emits preferentially over the same wavelength band. In fabricating the proposed sensors, electron-beam lithography was used to texture the surfaces of the emitter/bolometers for a much more precise and narrow wavelength selectivity. The textures were designed according to the principles of photonic-band-gap (PBG) structures, which are characterized by spatially periodic variations of refractive index that give rise to narrow "forbidden" wavelength transmission bands. This effect was exploited to make two-dimensional PBG structures in high reflectivity (low emissivity) material that preferentially emit infrared light predominantly in the desired, narrow bands when heated. An additional innovation was to take advantage of the exponential dependence of resistivity of single-crystal silicon on the temperature in the "intrinsic" conduction regime. This effect enhances the signal-to-noise ratio of the bolometer considerably and enables the manufacture of a small, low-power, high-sensitivity gas sensor.

*This work was done by Thomas George, Daniel Choi, and Eric Jones of Caltech for* **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to*

*Intellectual Property group*
*JPL*
*Mail Stop 202-233*
*4800 Oak Grove Drive*
*Pasadena, CA 91109*
*(818) 354-2240*

*Refer to NPO-20931, volume and number of this* NASA Tech Briefs *issue, and the page number.*

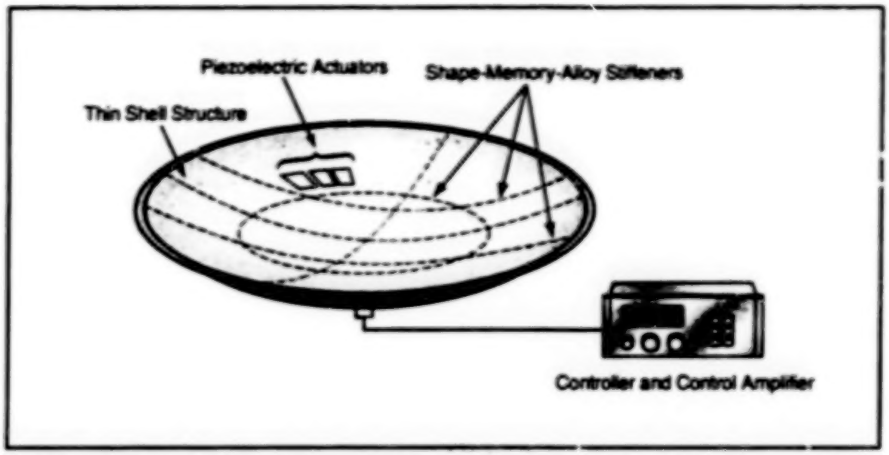
## Deployable Shell Structures With Shape-Control Actuators

Hierarchical distributed control systems would effect both deployment and fine shape control.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Advanced control systems that include built-in smart-material elastic-deformation structural actuators have been proposed for deployable thin-shell structures that are required to be maintained in precise shapes once deployed. This approach to structural shape control was conceived to enable the development of lightweight telescope mirrors, radar reflectors, and the like that could be stowed compactly for launching and transport, then deployed in outer space to required precise shapes at much larger dimensions (of the order of 10 m). The concept may also be applicable to similar, but probably smaller structures for terrestrial use.

A typical shell structure according to the proposal (see figure) would include (1) a flexible single- or multiple-layer face sheet that would include a reflective mirror surface; (2) structural supports in the form of stiffeners made of shape-memory alloys; and (3) bimorph-type piezoelectric actuators, possibly of a variety of sizes and shapes. The actuators, together with an electronic control subsystem, would implement a concept of hierarchical distributed control: The shape-memory actuators would be used for global shape control and would generate the large deformations needed for the deployment process. The piezoelectric actuators would generate smaller deformations and would be used primarily to effect fine local adjustments of the shape of the mirror.




**A Deformable Curved Mirror** of paraboloidal or similar shape would contain stiffeners, made of shape-memory alloys, that would also serve as global shape-control devices. In addition, piezoelectric actuators would serve as local shape-control devices.

Because of the geometric and material nonlinearities of shell structures, this work considers the essential nonlinearity of the large deformations needed for stowage and deployment, and the further complexity and nonlinearity that obtains in structures that include flexible membranes. This research and development effort will serve as a foundation for designing and building such structures integrated with hierarchical distributed control systems. The proposed work will take advantage of recent advances in mathematical modeling, dynamics, and distributed sensing and control of structures that exhibit nonlinear responses and undergo large deformations.

*This work was done by Gregory Hickey and Shyh-Shiuh Lih of Caltech and Horn-Sen Tzou of the University of Kentucky for* **NASA's Jet Propulsion Laboratory.** *Further information is contained in a TSP [see page 1].*

*NPO-21138*

## Magnetoelastic Vibration Dampers

Unlike viscoelastic dampers, these would be highly effective at low temperatures.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Magnetoelastic dampers have been proposed for use in suppressing vibrations of large motors and transformers that operate at temperatures below 100 K. [Also see "Progress in Magnetoelastic Vibration Dampers," (NPO-20887) on page 26 of this issue.] These dampers would be made of magnetostrictive materials — specifically, Tb/Dy alloys. It would not be necessary to use the rare and expensive high-purity grades of Tb/Dy; the commercial grade would suffice and may in fact be preferable.

Conventional dampers for such applications are based on viscoelasticity. Because viscoelastic damping involves movements of atoms and these movements become very small at low temperatures, viscoelastic dampers become ineffective at low temperatures.

In magnetostrictive materials, vibrational energy becomes damped through the movement of magnetic domains and the consequent dissipation of vibrational energy as heat. Because this effect is not diminished at low temperatures, magnetostrictive materials can be expected to be effective in damping vibrations at low temperatures. In a recent quasi-static experiment, a Tb/Dy alloy specimen was found to dissipate 30 percent of vibrational energy per stress-and-strain cycle at a temperature of 77 K. Moreover, it may be possible to increase the dissipation factor through the addition of small amounts of N, Ta, and/or other elements to Tb/Dy alloys and through changes in the processing conditions.

*This work was done by Jennifer Dooley, Brent Fultz, John Vaccio, and Robert Chave of Caltech for* **NASA's Jet Propulsion Laboratory.** *Further information is contained in a TSP [see page 1].*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to*

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*(818) 354-2240*

*Refer to NPO-20988, volume and number of this NASA Tech Briefs issue, and the page number.*

# Books and Reports

## Large-Aperture Telescope Synthesized From Small Mirrors

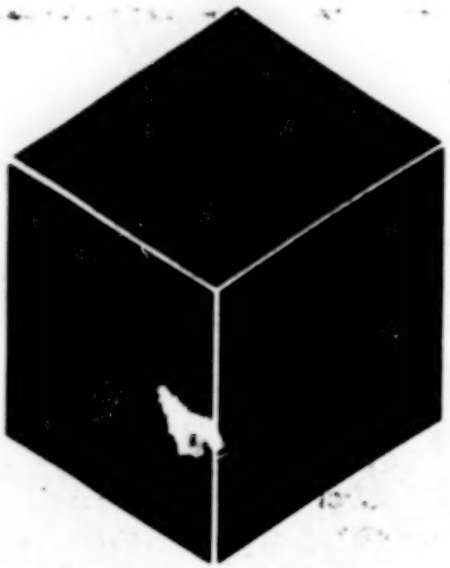
A report proposes a design concept for synthesizing a reflecting telescope with a large-aperture (diameter ≈100 m) primary mirror from a sparse arrangement of four smaller (diameter ≈10 m) primary mirrors. The telescope would be placed in orbit for viewing Earth with high resolution. The primary and secondary mirrors would be mounted on a lightweight structure that would be deployed in orbit. The primary mirrors would be mounted on a linkage that would include arms and actuators to rotate the arms. The resulting motion would be such that (1) the primary mirrors would stay on an imaginary spherical or parabolic surface centered on the stationary secondary mirror and (2) over a time interval of several minutes, the area swept out by the sparse primary mirrors would include the entire desired large aperture. The secondary mirror would be equipped with adaptive optics for image compensation. Images would be accumulated on the focal plane during frame periods of 0.2-s duration. Image data would be stored and processed to synthesize a full-aperture, high-resolution image from the sequence of sparse-aperture images.

*This work was done by Philip Moynihan of Caltech for* **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Ultra-Sparse Aperture Concentrator with Full-Area Coverage," see TSP's [page 1].*
*NPO-21103*

## Uplink/Downlink Spacecraft Radio Occultation Measurements

A report proposes a method to increase the accuracy of Doppler measurements made at the beginnings and endings of Earth/spacecraft radio occultations. Such measurements can reveal structural details of occulting objects in outer space. Heretofore, one-way measurements have been used, and have been subject to degradation of accuracy by frequency fluctuations of an onboard oscillator. In the proposed method, a spacecraft would be equipped with a Doppler extractor, and data from simultaneous uplink and downlink measurements would be combined in such a manner as to cancel the noise of the onboard oscillator to synthesize a phase and frequency reference with a stability determined by the stability of an atomic clock at the Earth station. The frequency stability is expected to be two to three orders of magnitude greater than in the prior method, with consequent increased sensitivity for investigating tenuous targets (e.g., planetary rings and atmospheres) and increased dynamic range within opaque regions. In addition, greater spatial resolution is expected to be available for mapping large- and small-scale target structures.

*This work was done by Massimo Tinto of Caltech for* **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Spacecraft radio occultations using multiple Doppler readouts," see TSP's [page 1].*
*NPO-30216*



# Materials

## Hardware, Techniques, and Processes


25 Stable Ohmic Contacts on SiC Devices for High Temperatures
25 Heat-Exchanger Rocket Engine
26 Refrigerant Blends Containing Trifluoroiodomethane
26 Electroceramic Actuators for Operation at Low Temperatures


## Books and Reports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## Stable Ohmic Contacts on SiC Devices for High Temperatures

The candidate material — $Ti_3SiC_2$ — is thermodynamically stable in contact with SiC.

*John H. Glenn Research Center, Cleveland, Ohio*

$Ti_3SiC_2$ has been proposed as a material for ohmic contacts on SiC-based electronic and microelectromechanical devices intended to operate at temperatures >600 °C and/or in corrosive environments. Although SiC is stable and devices made of SiC are capable of functioning at elevated temperatures and in corrosive environments, the lack of stable ohmic contacts has been a barrier to the realization of SiC-based devices. Most metals react with SiC at high temperatures, forming metal silicides and/or carbides. At a minimum, these reactions cause contact resistances to change over time, affecting the performances of devices; in extreme cases, entire contact layers can deteriorate through oxidation, melting, evaporation, or balling up on surfaces.

The proposal to use $Ti_3SiC_2$ was made on the basis of a search of the literature on transition-metal carbides, nitrides and borides; metal and compound contacts for SiC; phase stability diagrams; brazing; and methods of deposition. The properties of $Ti_3SiC_2$ were found to be exceptionally favorable for making highly stable ohmic contacts on SiC devices for operation at temperatures >600 °C and/or in corrosive environments.

$Ti_3SiC_2$ is thermodynamically stable in contact with SiC and is one of the products usually formed in reactions between thin Ti films and 6H SiC substrates after rapid thermal annealing. $Ti_3SiC_2$ has electrical conductivity greater than that of Ti or TiC, plus high thermal conductivity and acceptably large resistance to thermal shock. It is rigid, relatively light, and stable at temperatures up to 2,200 °C. Its coefficient of thermal expansion is roughly twice that of SiC; however, like gold, $Ti_3SiC_2$ relieves internal stress via motion of dislocations, even at room temperature. Oxidation of $Ti_3SiC_2$ follows a parabolic rate law over the temperature range of 900 to 1,400 °C in air, with an activation energy ≈4 eV. The oxidation product is a conformal protective layer of $TiO_2/SiO_2$. On the basis of published data, it has been estimated that after 1,000 hours in air at a temperature of 1,100 °F (593 °C) the thickness of the oxide film on $Ti_3SiC_2$ would be only ≈11 nm.

$Ti_3SiC_2$ can be deposited directly on SiC by sputtering, chemical vapor deposition, or pulsed laser ablation. Because of its thermodynamic stability in contact with SiC, $Ti_3SiC_2$ forms a stable interface with a stable electrical resistance. The one major drawback is that $Ti_3SiC_2$ reacts with most metals used for electrical interconnections, forming TiC and silicides. Hence, it may be necessary to develop diffusion barriers to enable the use of standard interconnection metals.

*This work was done by Harry L. Tuller, Marlene A. Spears, and Richard Micak of Boston Microsystems, Inc., for* **Glenn Research Center.**

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16982.*

## Heat-Exchanger Rocket Engine

Engine heat is used to prevaporize liquid oxygen.

*Lyndon B. Johnson Space Center, Houston, Texas*

The proposed rocket engine includes a combustion chamber actively cooled by liquid oxygen: Heat from the combustion chamber vaporizes the flowing liquid oxygen, and the absorption of latent heat of vaporization contributes to cooling of the combustion-chamber wall. The resulting high-vapor-quality (mostly vapor) two-phase flow of oxygen is then injected into the combustion chamber to burn with the fuel. Vaporization of the majority of the oxygen prior to injection renders the engine insensitive to wide variations of inlet conditions.

The need to reduce the sensitivity of the engine to inlet conditions arises because of a generic drawback of cryogenic rocket-engine propellants: In general, liquid oxygen and hydrocarbon fuels can be stored as propellants for rocket engines. Because liquid oxygen and other cryogenic propellants are very volatile, thermal-control devices are necessary for storing them. During operation of a cryogenic-fluid feed system of a rocket engine, there may be some nonuniformity in the level of subcooling, and/or vapor bubbles may appear in some locations. The resulting fluctuations in the quality of the liquid oxygen [that is, in the liquid fraction of the two-phase fluid] delivered to the engine can lead to malfunctions.

In designing and operating the proposed engine, no attempt would be made to inject liquid oxygen into the combustion chamber. On the contrary, most or all of the oxygen is vaporized prior to injection, in recognition of the fact that for oxygen and other highly volatile propellants, the magnitudes of flow-rate fluctuations are much smaller in the high-vapor-quality (mainly gas) regime than they are in the low-vapor-quality (mainly liquid) regime. As a result, the pattern of injection of oxygen into the combustion chamber, which pattern can be expected to exert a major effect on engine performance, is rendered much less sensitive to inlet quality variations than it would be if one were to attempt to inject liquid oxygen.

The proposed engine, denoted a heat-exchanger rocket engine, includes flow channels in its combustion-chamber wall. Liquid oxygen enters the engine through these channels. The rate of transfer of heat from the combustion process to the liquid oxygen flowing in the channels is adjusted so that most or all of the liquid oxygen is vaporized and the combustion-chamber wall temperature remains low. Mixing devices in the heat-exchanger flow passages enhance heat transfer in two-phase flow. The high-vapor-quality flow of liquid oxygen from the channels is collected in an oxygen-injector manifold and distributed in the combustion chamber through annular gaps at the head end of the combustion chamber.

Fuel is injected radially into the combustion chamber from a central injector extension. The fuel jets are broken up and atomized by the cross flow of gas. The injector configuration is selected to obtain a fuel-rich wall zone and adequate atomization; these features control engine performance and the rate of transfer of heat to the walls of the combustion chamber and nozzle. The fuel

injector is adjusted to control the amount of fuel landing on the chamber wall and, therefore, control the gas temperature driving the heat exchange.

In an alternative scheme, the gas flowing from the heat exchanger would be collected in tanks or other accumulators, then fed from the accumulators to the engine. In this scheme, the operation of the engine as a whole would be somewhat decoupled from the operation of its heat-exchanger portion. This scheme may present some advantages at an overall system level.

*This work was done by Jacky Cavignac of TRW Space & Technology Division for* **Johnson Space Center**.
*MSC-23081*

## Refrigerant Blends Containing Trifluoroiodomethane

Some of these non-ozone-depleting refrigerants can supplant older ozone-depleting ones.

*John F. Kennedy Space Center, Florida*

Blends of refrigerant fluids have been developed as improved alternatives to conventional chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants, which contribute to depletion of stratosphere ozone. Each blend of this type is a zeotropic or nearly azeotropic mixture of trifluoroiodomethane ($CF_3I$) with two or three hydrofluorocarbon (HFC) refrigerant compounds. In addition to having zero ozone-depletion potential, these $CF_3I$-containing refrigerant blends are nonflammable, and have low toxicity, low global-warming potential (GWP), and low total equivalent warming impact (TEWI). [GWP and TEWI are two measures that quantify different aspects of contributions to global warming.]

In comparison with prior non-CFC and non-HCFC refrigerants (including blends) that do not contain $CF_3I$, the present improved refrigerant blends containing $CF_3I$ offer greater energy efficiencies and smaller temperature glides. (The temperature glide of a zeotrope is the range of temperatures over which the zeotrope and its constituents evaporate and condense as the proportions of the constituents vary.) Some of the improved refrigerant blends can be substituted directly for older medium- and high-pressure refrigerants, without need to modify refrigeration equipment. The older refrigerants in question are R-12 (dichlorodifluoromethane), R-22 (chlorodifluoromethane), R-134a (tetrafluoroethane), and R-502 (a blend of chlorodifluoromethane and chloropentafluoroethane).

*This work was done by Jonathan S. Nimitz, Edward T. McCullough, and Patrick M. Dhooge of Nimitz, Inc., for* **Kennedy Space Center**.

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to*

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*Refer to KSC-12180, volume and number of this* NASA Tech Briefs *issue, and the page number.*

## Electroceramic Actuators for Operation at Low Temperatures

Relatively large strokes are produced at temperatures between 30 and 60 K.

*Marshall Space Flight Center, Alabama*

Electrostrictive ceramic actuators that can function at low temperatures have been developed for controlling the shapes of mirrors in the Next Generation Space Telescope (NGST). On Earth, electrostrictive ceramic actuators may be useful for fine control of the positions of objects in cryogenic laboratory apparatuses and in industrial cryogenic (including superconducting) systems.

On the basis of a number of candidate electroceramic materials, one material was found to be capable of a relatively large stroke in the temperature range of 60 K, such as to satisfy the specific stroke requirement for the NGST. Deformable mirrors that included actuators made from this material were assembled, using cutting and bonding techniques to form the material into actuators of the required sizes and shapes.

*This work was done by Maureen L. Mulvihill and Mark A. Ealey of Xinetics, Inc., for* **Marshall Space Flight Center**. *Further information is contained in a TSP [see page 1].*
*MFS-31634*

# Books and Reports

### Progress in Magnetoelastic Vibration Dampers

A report describes uniaxial-stress-versus-strain experiments that were performed on polycrystalline $Tb_{76}Dy_{24}$ alloy specimens. [Also see "Magnetoelastic Vibration Dampers" (NPO-20988) on page 21 of this issue.] The proposal is to use Tb-Dy alloys as vibration-damping materials at temperatures ≤100 K, exploiting the fact that in Tb-Dy alloys and other magnetostrictive materials, vibrations cause the movement of magnetic domains and the consequent dissipation of vibrational energy as heat. For one representative specimen, the Young's modulus at a temperature of 77 K was found to be only about one-fifth of that at 300 K. The large reduction in the Young's modulus below the Curie temperature of $Tb_{76}Dy_{24}$ (which is ≈180 K) is attributed to magnetoelastic strains that accompany the reorientation of magnetic domains under the applied stress. Large mechanical hysteresis — enough to damp as much as 19.2 percent of mechanical energy during one vibration cycle — was also observed in the specimen at 77 K. In addition, it is suggested that it may be possible to tune a Tb-Dy alloy damper by applying a magnetic field.

*This work was done by Jennifer Dooley, Robert Chave, Brent Fultz, Art Clark, Nathan Good, and Jason Graetz of Caltech for* **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "magnetoelastic damping applications of magnetostrictive ThDy alloys" see TSP's [page 1].*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to*

*Intellectual Property group*
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*(818) 354-2240*

*Refer to NPO-20887, volume and number of this NASA Tech Briefs issue, and the page number.*

## Development of Alternatives to Hydrazines as Propellants

A brief report summarizes an investigation of less-toxic alternatives to toxic monopropellant fluids used in launch vehicles, upper stages, and spacecraft propulsion. The toxic fluids in question are (1) hydrazine and its derivatives, used, variously, as fuels or by themselves as catalytically decomposable monopropellants; and (2) nitrogen dioxide, used as an oxidizer for such fuels. The investigation included tests of monopropellant mixtures containing such oxidizers as ammonium dinitramide (ADN), guanidinium dinitramide, ammonium nitrate, hydroxylammonium nitrate, and hydrazinium nitrate. The fuels in the mixtures included various alcohols, ammonia, and other amines. Water, ammonia, and alcohols were used to make the mixtures liquid, to increase the solubility of the components, and to depress the melting temperatures of the mixtures. Oxidatively balanced monopropellant formulations containing ADN as an oxidizer and formamide as fuel were produced. Hydrazine salts were also explored as both fuels and oxidizers; while more toxic than ADN, hydrazine salts are less harmful than hydrazines because their vapor pressures are much lower than those of hydrazines.

*This work was done by Paul E. Dr[illegible]nwell, Jeff C. Bottaro, and Mark A. F[illegible]e of SRI International for* **Glenn Re[illegible]arch Center**. *To obtain a copy of the report, "Development of new High-Performance Ammonium Dinitramide based and Hydrazinium Salt based Monopropel[illegible]nts," see TSP's [page 1].*

*Inquiries c[illegible]oming rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17143.*

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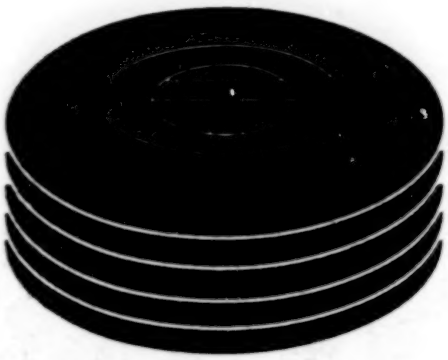

# Computer Programs


## Electronic Components and Circuits

31 Fourth-Generation Software for SEU Testing

## Physical Sciences

31 Software for Improved Processing of DRWP Signals
31 Software for Parallel Computation of 3D Thermal Convection
31 Software for Simulating Two-Phase Systems

## Mechanics

32 Software for Analyzing Traversability of Terrain

## Mathematics and Information Sciences

32 External Data and Attribute Hyperlink Programs for Promis•e®

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# Electronic Components and Circuits

## Fourth-Generation Software for SEU Testing

RBK4 is a computer program for testing electronic components for susceptibility to single-event upsets (SEUs). RBK4 controls the computer on which it is executed to communicate with both the board holding the device under test (DUT), a power supply, and other laboratory instruments including custom circuitry integrated into the computer. Written for the Windows 95, 98, and NT operating systems, RBK4 offers improvements over RBK3, its DOS-based predecessor. RBK4 enables the user to open, change entries in, and save configuration files that set the values of virtually every changeable field in the software. Information in the configuration files includes names and settings of counters, power-supply settings (including voltage, current, and limiting values thereof), soft-programmable switches, and full control over instrumentation displays. Clock circuits on the board can be enabled and disabled while counters integrated into the computer can be monitored and time-tagged. The software provides for full control of the power supply, including the control and monitoring of voltages and currents in the power supply and a variety of error and reset conditions. The data collected during a test run can be stored in the computer with a variety of viewing modes integrated into the software such as text file viewing and graphical plots, providing for easy, quick analysis of the test data.

*This program was written by Richard Katz of* **Goddard Space Flight Center** *and Igor Kleyner and Ingrid Brill of Orbital Sciences Corp. Further information is contained in a TSP [see page 1].*
*GSC-14399*

# Physical Sciences

## Software for Improved Processing of DRWP Signals

The Automated Adaptive Signal Processing (AASP) computer program extracts wind data from the outputs of Doppler-radar wind profilers (DRWPs). Unlike prior software used for this purpose, AASP does not rely on manual intervention to prevent a DRWP system from locking onto and tracking interfering signals (e.g., signals from side lobes of radar beams). AASP identifies interference signals in the range-gated spectra produced by a DRWP, then tracks the height- and time-continuous atmospheric signal in each radar beam. AASP then combines the radial velocity components from three or five beams and computes the horizontal and vertical wind components. AASP produces high-quality wind profiles within a single radar cycle, without need for averaging for quality control. It also calculates an indication of the level of confidence with each wind estimate. The single-cycle capability enables users to detect temporal shifts in wind earlier and with greater confidence than was possible by use of prior software. AASP comprises two coupled software subsystems: (1) a subsystem that implements signal-processing algorithms and (2) a subsystem that provides a quality-control capability and that generates displays of spectra, of wind estimates, and of the performances of the DRWP hardware.

*This work was done by Robin Schumann, Ed Toughlian, Greg Taylor, and Erik Magnuson of ENSCO, Inc., for* **Kennedy Space Center**.
*KSC-12245*

## Software for Parallel Computation of 3D Thermal Convection

A computer program solves the differential equations of three-dimensional (3D) thermal convection of an incompressible fluid by use of a parallel-processing, finite volume numerical scheme. The equations of conservation of momentum, and energy are integrated over macroscopic control volumes on a normal, staggered grid. Upwind interpolation functions are used to prevent spurious numerical oscillations at high Rayleigh numbers. The resulting discretized equations, including a pressure equation that demands most of the computation time, are solved by a parallel-processing, multigrid method. The multigrid aspect of the method involves the use of a hierarchy of grids of different mesh sizes to obtain a solution on the finest grid. It has been proven, both theoretically and practically, that the multigrid aspect affords rapid convergence on a solution. The program could be used, for example, to predict oceanic convection currents. The effectiveness of the program has been demonstrated by applying it to test cases on several parallel-computing systems.

*This program was written by Ping Wang of Caltech for* **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

*This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-21147.*

## Software for Simulating Two-Phase Systems

Møtran (signifying "multi-phase transient") is a package of software for simulating flows in two-phase (gas/liquid) fluid systems like networks of such components as pipes, T junctions, pumps, evaporators, and condensers. The software is based on a two-fluid formulation that can accommodate unequal velocities and temperatures for the two phases. Møtran provides for single-phase, bubbly, slug, stratified, and annular flow regimes. Mechanistic models are used for establishing the boundaries between flow regimes and for constitutive relations that represent wall shear, interfacial shear, wall heat transfer, interfacial heat transfer, and phase change. Constitutive models are provided for each of the flow regimes, and all are selected and calculated dynamically during solution for each grid point in the network. The software is applicable at all levels of gravitation, whether steady or time varying. Møtran includes a state-of-the-art graphical user interface (GUI) and an integrated fluid-property database. The user assembles the representation of the fluid system (which can be of arbitrary topology) through drag-and-drop operations on the GUI. The software predicts pressures, volume fractions, temperatures, and velocities of the phases throughout the system.

*This program was developed under the direction of James J. Barry and Christopher J. Crowley of Creare Inc. for* **Glenn Research Center**. *For further information, please contact James J. Barry at (603) 643-3800 or via http://www.creare.com/motran/index.html.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16937.*

# Mechanics

## Software for Analyzing Traversability of Terrain

Grid-Based Estimation of Surface Traversability Applied to Local Terrain (GESTALT) is a software library that helps a robotic wheeled vehicle choose a safe path across nearby terrain. The input to GESTALT consists mainly of three-dimensional range measurements of the nearby terrain taken by sensors (e.g., stereoscopic cameras or a laser scanner) aboard the robot as it moves along. GESTALT groups the data into grid cells, then geometrically evaluates the cells as separate planar patches, identifying such impediments to traversability as steps, steep slopes, and excessive roughness. Both straight and curved paths from present position of the robot can be evaluated. The safest path that helps the rover move toward its goal is selected. The resulting path evaluations can be used to steer the robot.

GESTALT is an extension of a previously developed algorithm known as Morphin, incorporating additional capabilities: Diagnostic outputs in greater detail are available. Traversability can be evaluated in a direction-specific manner; for example, a hill found to be unclimbable if approached head-on might be found climbable on a sideways approach. Navigation parameters can be reset at any time. Multiple rover configurations can be evaluated in a single map.

*This program was written by Mark Maimone of Caltech for* **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

*This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-21233.*

# Mathematics and Information Sciences

## External Data and Attribute Hyperlink Programs for Promis•e®

External Data and Attribute Hyperlink are computer programs that can be added to Promis•e®, which is a commercial software system that automates routine tasks in the design (including drawing schematic diagrams) of electrical control systems. The programs were developed under the Stennis Space Center's (SSC's) Dual Use program to provide capabilities for SSC's 3 MCS configuration management system, which uses Promis•e®. The External Data program enables the storage and management of information in an external database linked to a drawing. Changes can be made either in the database or on the drawing. Information that originates outside Promis•e® can be stored in custom fields that can be added to the database. Although this information is not available in Promis•e® printed drawings, it can be associated with symbols in the drawings, and can be retrieved through the drawings when the software is running. The Attribute Hyperlink program enables the addition of hyperlink information as attributes of symbols. This program enables the formation of a direct hyperlink between a schematic diagram and an Internet site or a file on a compact disk, on the user's hard drive, or on another computer on a network to which the user's computer is connected. The user can then obtain information directly related to the part (e.g., maintenance, or troubleshooting information) associated with the hyperlink.

*This program was written by Rich Derengowski and Andrew Gruel of ECT International for* **Stennis Space Center**.

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

*ECT International*
*4100 N. Calhoun Road*
*Brookfield, WI 53005*
*Tel. No. (262) 781-1511*

*Refer to SSC-00135, volume and number of this* NASA Tech Briefs *issue, and the page number.*

# Mechanics

## Hardware, Techniques, and Processes


35 "Smart" Actuators for Alleviating Buffet of Aircraft
36 Uncertainty Models From Ground Vibration Testing
36 Equipment for Removal of EDM Water Filters
37 Mechanisms Facilitate Blowdown of Large Diesel Engines
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# "Smart" Actuators for Alleviating Buffet of Aircraft

Peak stresses could be reduced without sacrificing control authority.

*Dryden Flight Research Center, Edwards, California*

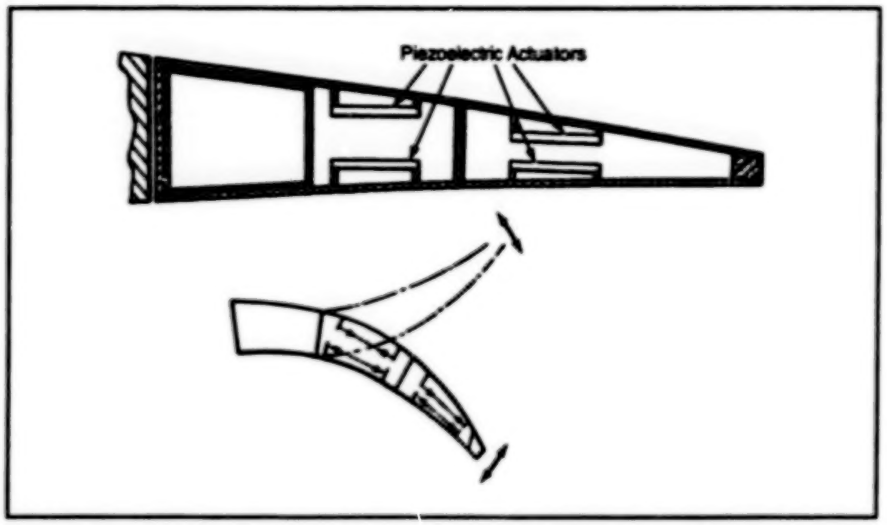



**Figure 1. Piezoelectric Actuators are built into a control surface in a configuration to enable controlled deformation of the surface.**

An active-control surface modal (ACSM) device has been developed as an improved means of alleviating buffet of an aircraft. The ACSM device is a "smart" actuator system that includes an array of antagonistic piezoelectric actuators installed within a rudder or other aircraft control surface (see Figure 1). These actuators are used to deform the control surface in what amounts to controlled vibration modes (see Figure 2), the frequencies and mode shapes being chosen to affect unsteady aerodynamic damping to suppress the dynamic effects of buffet.

Buffet is a turbulent airflow phenomenon that originates from the separated flow shed behind aerodynamic lifting surfaces of an aircraft. An instability in this flow gives rise to random fluctuations of pressure that excite vibrations of the tail surfaces of the aircraft. These vibrations contribute to fatigue damage and thus to life-cycle cost and maintenance time.

Prior to the development of the present ACSM, both passive and active methods of alleviating buffet were considered. The passive methods included the use of fences and other modifications to minimize the strengths of shed vortices. Active methods included, variously, the use of hydraulic or piezoelectric actuators to superimpose, upon control motions, oscillations of the affected control surfaces about their hinges to affect aerodynamic damping. The two major shortcomings of this prior active method are the following: (1) For a given aircraft, the flight-control system and the buffet-load-alleviation control system must use the same degree(s) of freedom of the same control surface(s), so that the availability of the control surface(s) for each role (flight control or alleviation of buffet) is reduced. (2) Because it is difficult to make a massive control surface oscillate about its hinge at a high frequency, operation is limited to relatively low frequencies.

The use of piezoelectric actuators in an ACSM device to deform a control surface (in contradistinction to trying to make the control surface oscillate about its hinge) makes it possible to use modal frequencies that are high enough to encompass the frequency spectrum of buffet, gusts, and flutter. Although the ACSM is an integral part of the rudder or other control surface, it can be actuated according to control laws independent of those of flight-control system; hence, the control surface can respond to flight-control commands as well as the dynamic buffet-load-alleviation signals.

The vertical tail of the F-18 airplane was selected for benchmark case study for a demonstration of the ACSM approach to alleviation of buffet loads. Buffet-load data generated by NASA Langley Research Center in experiments on a 16-percent-scale model of the F/A-18 airplane were used in the study. Frequency-response analyses were performed for open- and closed-loop-control test cases. In the closed-loop case, two acceleration signals measured at leading and trailing edges of the tail tip section were used as the feedback signals to command the actuators. These analyses showed that the use of the ACSM device would reduce peak tail-root stresses by 60 to 80 percent; this would translate to an eight-fold enhancement of the fatigue life of the vertical tail. The maximum total actuator power needed to effect this reduction was found to be 182 W. It was also concluded, from the results of these analyses, that gust loads could be alleviated and flutter suppressed by use of the ACSM device.

**Figure 2. These Examples of Mode Shapes are typical of rudder deformations generated by an ACSM to reduce buffet loads.**

*This work was done by K. Appa and J. Ausman of Appa Technology Initiatives, K. S. Khot of the Air Force Research Laboratory, and Martin Brenner of* **Dryden Flight Research Center.** *Further information is contained in a TSP [see page 1].*

*DRC-01-25*

# Uncertainty Models From Ground Vibration Testing

Test data indicate least conservative errors in model.

*Dryden Flight Research Center, Edwards, California*

Structural dynamics are often an important consideration when evaluating system characteristics. A concern related to structural dynamics is the analysis of flutter for a flight vehicle. The instability associated with flutter can be quite sensitive to the structural dynamics; therefore, analysis of robustness with respect to error, or uncertainty, is becoming increasingly important for the flight test community. In particular, uncertainty models are needed for μ-method analysis as described in "Characterizing Worst-Case Flutter Margins From Flight Data" (DRC-97-03), *NASA Tech Briefs*, Vol. 21, No. 4 (April 1997), page 62.

A method of determining optimal uncertainty descriptions for models of structural dynamics has been developed. This method results in the smallest uncertainty descriptions that are needed to account for data measured during ground vibration testing. Consequently, the resulting models generate least-conservative predictions of the flight conditions that are associated with flutter.

A ground vibration test is commonly performed as a pre-flight check that attempts to evaluate the quality of an analytical model. The basic concept is to excite the structural dynamics and measure responses at locations throughout the vehicle. The responses are then analyzed to estimate a set of modal properties such as natural frequencies and mode shapes. These modal properties are compared with the analytical model to determine the error and uncertainty in the model.

| Norm | Flutter Speed (knots) |
|---|---|
| 1 | 317 |
| 2 | 343 |
| ∞ | 359 |

**Robust Flutter Speeds** were computed by 1-, 2-, and ∞-norm analyses.

In reality, there are many estimates of modal properties that result from a ground vibration test. There may be hundreds of sensors that indicate slightly different estimates of natural frequencies. Also, the mode shapes are computed by a routine that interpolates responses from many sensors. Different interpolation schemes result in different estimates of modal properties.

The traditional method of analyzing test data is to generate modal properties that are a 2-norm minimization, or average, of a set of property estimates. The new method of analyzing test data is to use an ∞-norm minimization. The ∞-norm approach does not generate the optimal property; rather, it generates the optimal uncertainty set that is associated with the property. In this way, μ-method analysis of the resulting model generates least-conservative predictions of robust stability.

A wing testbed was used to demonstrate this concept. Ground vibration tests of the wing were performed to generate estimates of modal properties. The optimal properties and their associated errors were formulated using 1-norm, 2-norm, and ∞-norm analyses. Robust flutter speeds were computed for models with each set of optimal properties with respect to their associated errors. The results are given in Table 1. These results indicate that the highest, or least-conservative, flutter speed is computed for the model that uses modal properties and uncertainty from ∞-norm analysis.

*This work was done by Starr Potter and Rick Lind of* **Dryden Flight Research Center**.

*DRC-01-54*

# Equipment for Removal of EDM Water Filters

The risk of back injuries is reduced.

*John H. Glenn Research Center, Cleveland, Ohio*

An assembly of lifting equipment has been devised to enable the safe removal of water filters used in electrical-discharge machining (EDM). As explained below, this equipment prevents injuries of a type formerly associated with changing the filters.

In the particular machine shop in which the equipment is used, there are seven EDM machines, each equipped with filters located in a water tank at about knee level. The filters must be changed at intervals of operating time that range from 10 to 200 hours, depending on the material being cut. A filter to be removed is full of water and weighs about 50 lb (≈23 kg). The filter must be held in place while the water drains out before completing its removal. Previously, the filters were changed by hand, without the help of any equipment. Some workers suffered back injuries from bending over, lifting the water-laden filter elements, and holding them while the water drained out.

The present lifting equipment prevents these injuries by changing the nature of the lifting operation. The equipment includes a special-purpose tool on one end of a cable, the other end of which is wound on a ratcheting hand crank. The tool includes a part that is mounted on the inner diameter of a filter element on an outlet shaft. The tool also includes lifting arms that are lowered and attached to the outside diameter of the filter. Once the tool has been attached to the filter, the hand crank is actuated to raise the filter partly out of the tank. Once the water has drained out of the filter element, a worker can safely lift the filter element and the tool out of the tank. The filter is then disconnected from the tool and discarded.

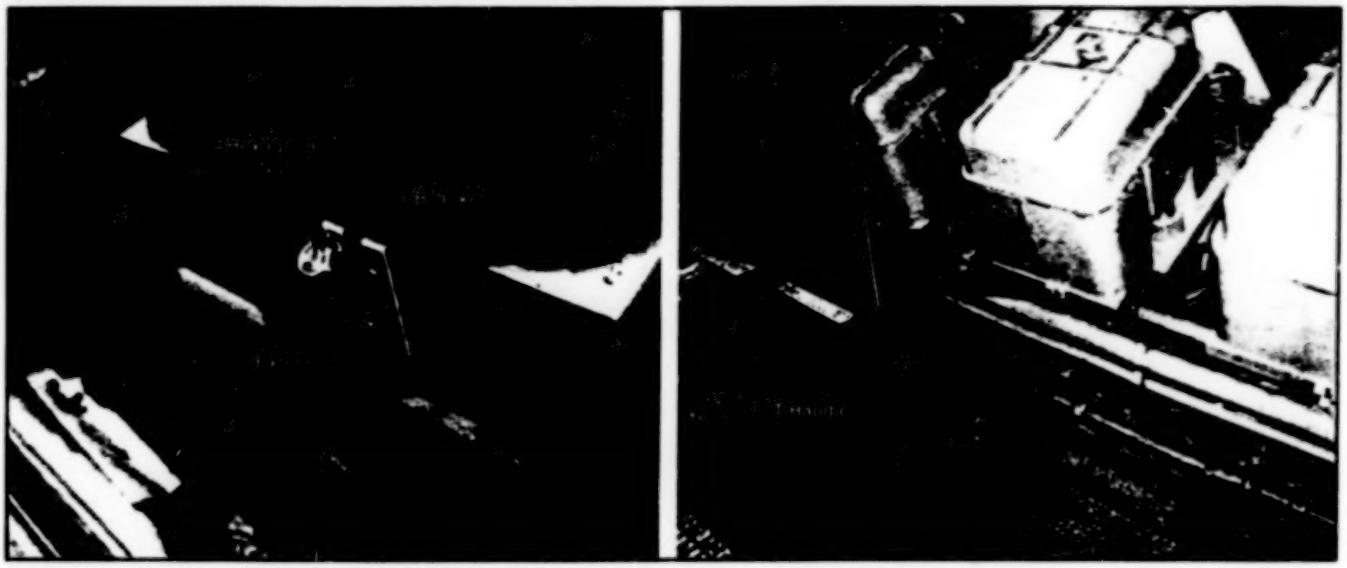
*This work was done by Timothy G. Schilens of Microcraft Inc. for* **Glenn Research Center**.

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16795.*

## Mechanisms Facilitate Blowdown of Large Diesel Engines

Blowdown can be performed faster, more easily, and more safely.

*Stennis Space Center, Mississippi*



**A Simple Mechanism — similar to a combination of wrench extensions used to turn a difficult-to-reach nut or bolt on an automobile engine — is installed permanently to bring the point of actuation of a Kenny cock out to a readily accessible and visible location.**

Simple mechanisms have been devised to facilitate the blowdown of large diesel engines. As explained below, these mechanisms reduce the amount of time and effort that must be expended to test engines before operating them.

Blowdown is a procedure used to detect fuel or water leaks in diesel-engine cylinders. To prepare for blowdown, a technician opens a valve, known as a Kenny cock, on each cylinder. The engine is then cycled. If fuel or water has leaked into a cylinder, it is ejected through a drain pipe and can be seen. Once blowdown has been completed, the Kenny cocks are closed. If no water or fuel was found during blowdown, the engine can be started.

In the setting for which the present blowdown-facilitating mechanisms were devised, the Kenny cocks are difficult to see and reach, and they are opened and closed by turning hexagonal bolts. Before these mechanisms were installed, technicians had to squat or get down on their knees in order to do see, open, and close the Kenny cocks. The combination of difficulty and awkwardness of position contributed substantially to the time and effort of the blowdown procedure and increased the risk of injury.

The blowdown-facilitating mechanisms consist of components attached permanently to the Kenny cocks plus at least one component that a technician carries from cylinder to cylinder. One of the components attached permanently to the Kenny cock on each cylinder is a swivel socket that fits onto the hexagonal bolt. An extension is attached to the swivel socket and is supported by a bracket, through which it protrudes. A hexagonal nut is attached to the end of the extension (see figure).

The component carried by the technician is a T-handle shaft with a hexagonal socket attached to tip of the shaft. The technician simply mates the hexagonal socket with the hexagonal nut and turns the handle to open or close the Kenny cock. Because the hexagonal nut is readily visible, blowdown can be performed in less time and with less difficulty and risk. In the original setting, use of these mechanisms has reduced the time needed to perform blowdown by about 60 percent.

*This work was done by Tim Delcuze, Ira Lossett, Todd Pearson, Jerry Quinn, James Seals, Danny Tarter, and Rodney Wilkinson of Lockheed Martin Corp. for* **Stennis Space Center**. *Further information is contained in a TSP [see page 1].*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Stennis Space Center [see page 1]. Refer to SSC-00132.*

## Improved Lightweight Freeze-Tolerant Tubes

Improved designs have been conceived for lightweight tubes that can withstand the large (as much as 8 or 9 volume percent) freeze/thaw expansions and contractions of typical heat-transfer fluids like water and ammonia. Intended originally for radiators for rejecting waste heat from spacecraft, these designs may also be suitable for such terrestrial applications as freeze-tolerant water pipes in houses and sprinkler systems. Typical prior freeze-tolerant-tube designs are characterized by short operating lives because they rely on compressible polymeric inserts that are degraded by permeability and by embrittlement at low temperatures. The improved designs call for thin tube walls with noncircular (typically oval) cross sections and solid or hollow metal inserts of various shapes, all selected together to obtain specific combinations of limited volume expansion and mechanical advantage such that the stresses in the tube walls remain sufficiently low under all anticipated freeze/thaw conditions.

*This work was done by Robert J. Copeland and Mark M. Weislogel of TDA Research for* **Johnson Space Center**. *Further information is contained in a TSP [see page 1].*

*MSC-23120*

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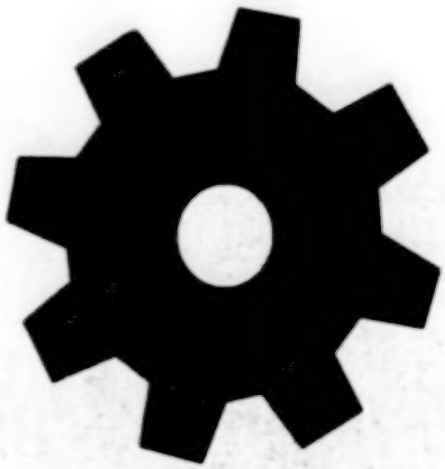

# Machinery

## Hardware, Techniques, and Processes


41 Six-Legged Experimental Robot

41 Three-Fingered Robot Hand With Self-Adjusting Grip

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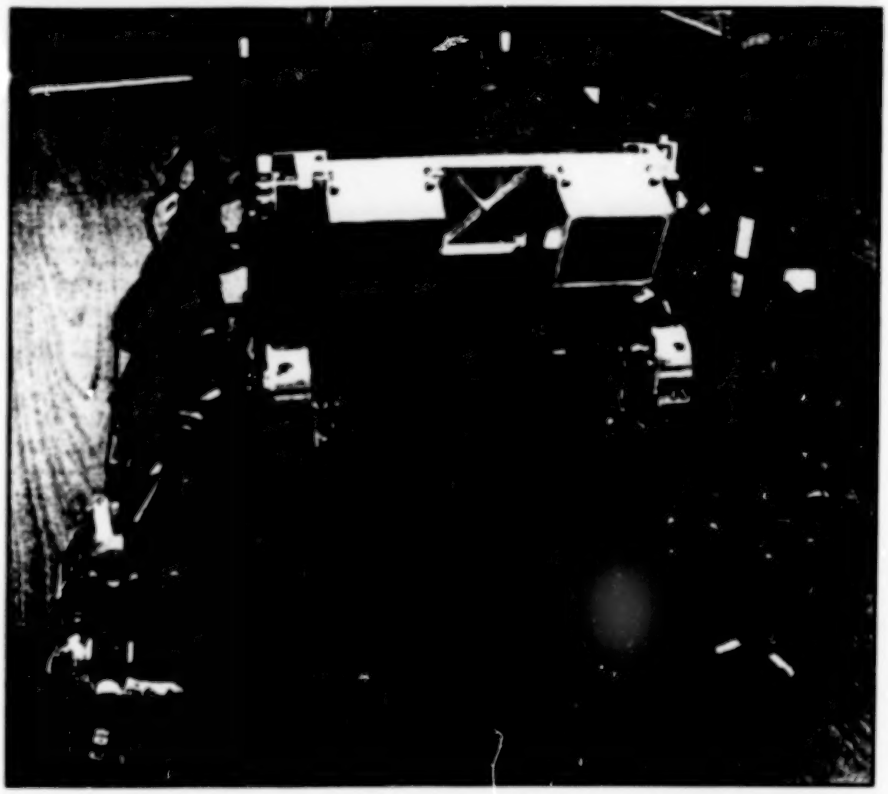
## Six-Legged Experimental Robot

This robot would walk to a designated location and perform mechanical operations there.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

The figure depicts the Legged Excursion Mechanical Utility Robot (LEMUR) — a six-legged robot for demonstrating robotic capabilities for assembly, maintenance, and inspection. LEMUR is designed to be capable of walking autonomously along a truss structure and to perform other operations.

LEMUR is equipped with stereoscopic video cameras and image-data-processing circuitry for navigation and mechanical operations. It is also equipped with a wireless modem for remote operations. Upon receipt of a command via the modem, LEMUR would walk along the truss structure toward a mechanical assembly at a prescribed location. Once LEMUR was within a distance of 1 m from the assembly, its artificial-vision system should be able to recognize the image of the assembly and enable the LEMUR to move autonomously toward the assembly. Upon arrival at the assembly, LEMUR would perform simple mechanical operations with one or both of its front legs. It could also transmit images to a host computer.



This **Six-Legged Robot** would be used to demonstrate robotic capabilities for assembly, maintenance, and inspection.

Each of the six legs of the LEMUR is operated independently. Each of the four rear legs has three degrees of freedom (DOFs), while each of the front two legs has four DOFs. The front two legs are designed to hold, operate, and/or be integrated with tools. For example, the right front leg could be made capable of holding and turning a wrench socket, while the left front leg could be equipped with a hand, which could include an in-line macroscopic camera. The kinematic design of the LEMUR is such that it could support itself on the four rear legs, or, preferably, on three of them. The feet on the rear legs are capable of grappling.

LEMUR includes an onboard computer containing a Pentium (or equivalent or better) processor with a minimum speed of 200 MHz, a dynamic random-access memory of at least 32MB, and an assortment of digital control circuits, digital input/output circuits, analog-to-digital converters for input, and digital-to-analog (D/A) converters for output. Feedbacks from optical encoders in the leg actuators are utilized for closed-loop microcomputer control of the positions and velocities of the actuators. Signals for controlling motors in the actuators are generated by D/A converters and multiplexed through a sample-and-hold circuit. The multiplexed outputs are sent to pulse-width-modulator circuits, the outputs of which would constitute the control voltages applied to the motors.

LEMUR contains a rechargeable-battery power supply that could sustain operation for 1 hour. It would also be capable of operation through an electrical umbilical cord. Optionally, the umbilical cord could serve as a bypass for the wireless modem.

*This work was done by Gregory Hickey and Brett Kennedy of Caltech for* **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

*NPO-20897*

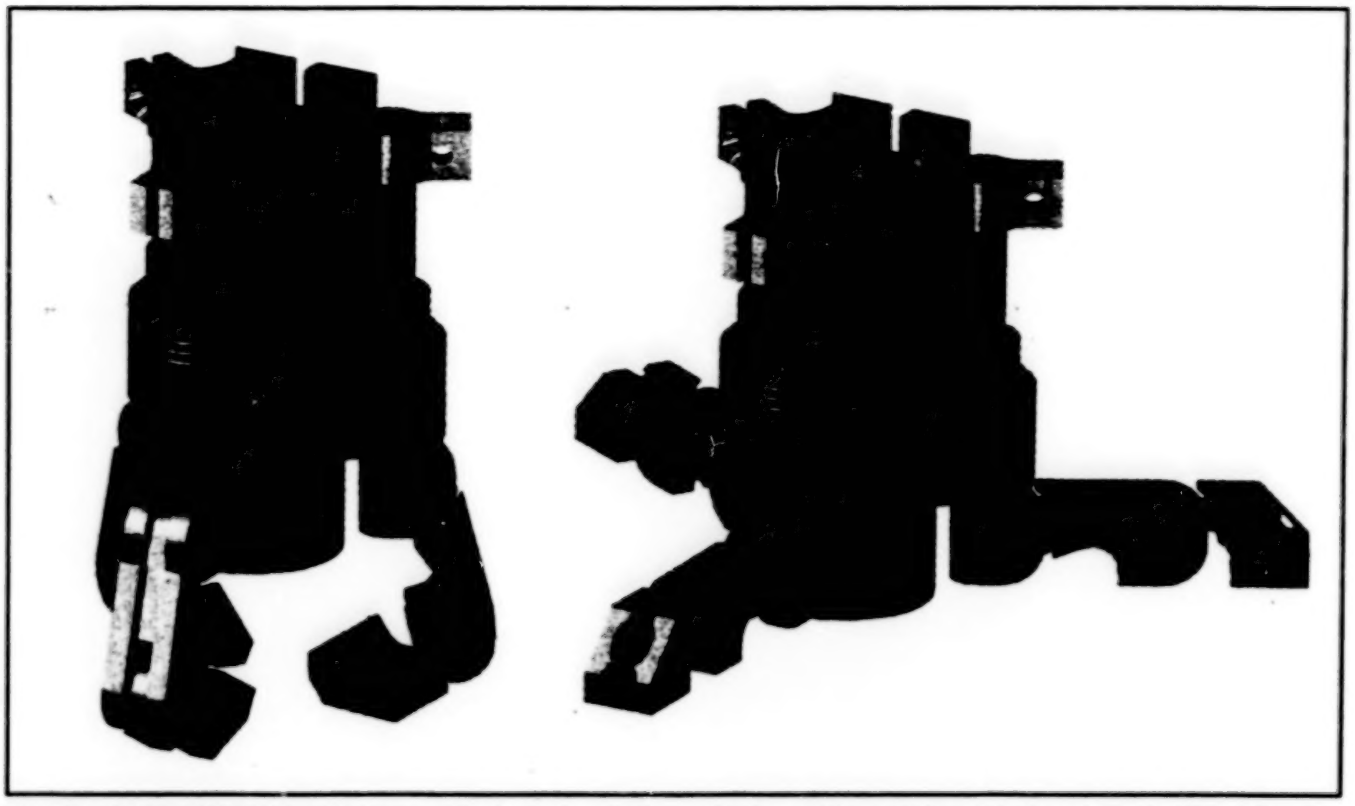
## Three-Fingered Robot Hand With Self-Adjusting Grip

Three fingers are actuated by one motor, tendons, and springs.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

The figure depicts a tendon-driven, three-fingered robot hand (or foot, depending on one's perspective) designed to be installed on the end of the left front leg of the six-legged robot described in the preceding article. This hand, which was undergoing development at the time of reporting the information for this article, is intended to satisfy the need for a small, lightweight mechanism that can grasp objects of various shapes (e.g., balls or cylinders of differing diameters), without need for an elaborate electronic control system or for multiple actuators. The hand also houses rudimentary sensors: the terminal optics of a fiber-optic camera are incorporated into the palm of the hand, and the housing for the optics doubles as a contact-sensor switch.

Each finger includes two links, with knucklelike joints. The knucklelike joint at



**This Three-Fingered Robot Hand features a relatively simple actuation mechanism, yet it can grip irregularly shaped objects. When fully open, it spans a diameter of about 2 in. (≈5 cm).**

the inner end of the innermost link is mounted on a base that pivots around an axis perpendicular to the joint axis, thereby allowing the finger to rotate into conformation with the object to be gripped. The three fingers are spring-biased into planes of action 120° apart, but forces and torques of contact with a gripped object overcome the spring biases, causing the finger to pivot into the aforementioned conformation.

For the sake of simplicity, the tendons that drive all three fingers are, in turn, driven by only one motor. More specifically, the motor drives a winch to which are coupled a set of tendons arranged as finger flexors. When these tendons are drawn in, the fingers close around the gripped object. For opening the fingers to release the gripped object, the fingers are equipped with a second set of spring-loaded tendons arranged as finger extensors. Each flexor tendon is connected to a spring stiffer than that of the corresponding extensor tendon; this provision prevents the full contact of one finger with the object from acting as a hard stop against the further closure of the other fingers, thereby enabling the fingers to conform to an irregularly shaped object.

*This work was done by Brett Kennedy of Caltech for* **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

*NPO-20907*

## Motorized Rotator for an Ultrasonic Probe

The probe can be positioned more precisely than before.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

An apparatus has been devised to enable accurate, reproducible angular positioning of an ultrasonic probe used to diagnose the carotid artery. More specifically, the apparatus is intended for use in a clinical setting in which the intima-media thickness (IMT) of the carotid artery is measured by use of information in ultrasound images. The IMT is useful as an indication of the health status of the carotid artery.

Ultrasonic probes are used to obtain longitudinal-view images of the carotid artery. The IMT can then be measured from these images. However, in order to obtain these images, it is necessary first to find the appropriate site with a transverse view and then to rotate each ultrasonic probe 90°. Heretofore, the probe has been rotated manually and without the benefit of a fixed reference.

The present apparatus includes a holder that accommodates various ultrasonic probes, and a cylindrical housing that rests on the patient's neck, acts as an anchor, and provides a fixed reference. A small stepping motor in the housing is coupled to the holder through gears. An electronic control unit sends control pulses to the motor when either a panel switch or a foot switch is pressed. The control pulses cause the motor to turn the holder, and thus the probe, by 90°. A second actuation of the switch causes the motor to rotate the probe back to the original angle.

The advantage afforded by this apparatus is greater (compared to manual rotation) accuracy in returning to a specific site in the carotid artery. The disadvantage is that the apparatus adds weight and bulk to the probe.

*This work was done by Helenann Kwong-Fu, Paul L. Lee, and Robert Sabor*

*of Caltech and Howard Hodis of USC for* **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to*

*Intellectual Property group*
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*Pasadena, CA 91109*
*(818) 354-2240*

*Refer to NPO-21244, volume and number of this NASA Tech Briefs issue, and the page number.*

# Books and Reports

## Measuring Turbomachine-Blade Deflections in Two Dimensions

A report describes a method of simultaneously measuring steady-state axial and tangential turbomachine-blade deflections by use of fiber-optic probes and probe actuators designed specifically for this purpose. Each fiber-optic probe illuminates a small spot and, by measuring a change in the amount of reflected light, detects the passage of a leading or trailing edge of a blade through the spot. Each probe actuator contains a servomotor that produces controlled, small increments of rotation of an eccentric probe mount to adjust the axial and tangential position of a probe. At each rotational speed, the passage of a leading or trailing edge of interest is found by adjusting the position of a probe until the blade-passage output pulse of the probe is just discernable above noise. When this has been done for all probes and/or edges of interest, the edge-passage times are determined in relation to the time of a once-per-revolution master pulse generated by an independent optical sensor. Then the blade deflections at a given speed, relative to those at a reference speed, are determined from the known probe positions and the measured blade-passage pulse times at both speeds.

*This work was done by Anatole P. Kurkov of* **Glenn Research Center** *and Harbans S. Dhadwal of Integrated Fiber Optic Systems, Inc. To obtain a copy of the report, "Simultaneous Optical Measurements of Axial and Tangential Steady-State Blade Deflections," see TSP's [page 1].*

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17200.*

## Designs for Safer Launching of Spacecraft Fission System

A report proposes the development of two different mechanisms that would prevent inadvertent startup of reactors in nuclear-fission-based propulsion and power systems in future spacecraft. The purpose of this development is to contribute to safety by ensuring that radioactivity is kept to normal negligible levels before and during launch and in the event of a launch accident. A reactor would incorporate one of two types of mechanisms. The first type would be launched with a subcritical set of fuel rods in the core and the remaining fuel rods held in a magazine external to the core. Once the spacecraft was safely in outer space, the magazine would rotate into place fueling the core. The second type of mechanism would employ fuel/absorber rods pushed into place to complete the core. These assemblies would consist of a neutron-absorbing material on one side and a fuel material on the other. The neutron-absorbing section in the core would both increase the margin against criticality and prevent the insertion of the fuel-material section of fuel/absorber rods. Again, once the spacecraft was safely in outer space, a motor would actuate a linear screw that would move the fuel section of the rods into the core, enabling the reactor.

*This work was done by Thomas Godfroy of* **Marshall Space Flight Center**. *To obtain a copy of the report, "Mechanism for Ensuring Absolute Safety During Launch of Fission Propulsion Systems," contact Marshall Space Flight Center [page 1].*

*MFS-31533*

## Spacecraft Nuclear Reactor Would Be Fueled in Orbit

Two reports summarize progress thus far in the continuing development of a spacecraft nuclear reactor, some or all of the fuel rods of which would not be loaded until the spacecraft was in orbit. (Keeping the fuel rods out of the reactor core before and during launch is intended to minimize the risk of release of radioactive material in the event of a launch accident.) The report describes the design and operation of the fueling mechanism, and problems in the design and fabrication of the core. The fuel rods include uranium oxide in thorium sleeves. The core includes niobium star-cross-section inserts and molybdenum tubes, into which the fuel rods are to be inserted. Techniques for brazing molybdenum parts were developed. A notable feature of design and operation is a provision to increase fuel-rod/molybdenum-tube thermal conductance by brazing the fuel rods into the tubes shortly after insertion, using heat generated by the reactor itself. The brazing material (vanadium) was selected to satisfy requirements to melt in the anticipated temperature range and is believed, but not proven, not to degrade other structural materials after long times at the high operating temperature in a high neutron flux.

*This work was done by Peter Ring of Advanced Methods & Materials for* **Marshall Space Flight Center**. *To obtain copies of the reports, "Safe 300 In-Space Refueling" and "Heat Pipe Power System (HPS) In Space Fueling A Simplified Approach," contact Marshall Space Flight Center [page 1].*

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# Compressed Symbology — Making Its Mark at NASA

The bar-code concept has been generalized into a powerful method of tracking manufactured parts.

*Marshall Space Flight Center, Alabama*

Compressed symbology is a product-identification method that was pioneered by NASA for tracking space-shuttle parts and is now being used to mark everything from groceries to automobile parts. Based on a system of two-dimensional marks applied to parts, compressed symbology was developed at NASA's Marshall Space Flight Center in response to the inherent need in the aerospace industry to track parts for configuration management.

The focus at Marshall is on ensuring the quality and safety of products. To be certain of the integrity of a product, each part must be tracked every step of the way — where it was made, who touched it along the way, and when and where it is installed. For NASA, that means tracking millions of parts — even tiny electrical parts no larger than a dime. Since bar codes were implemented in the mid-1980s, they have been used extensively and have saved NASA millions of dollars annually through automatic entry of data from manufacturing work orders and other paper media. However, bar-code labels have not worked well on some parts, especially small ones. Even in cases in which adhesive bar-code labels have been small enough, labels have come off, contaminating processes with glue and paper, and thereby giving rise to additional cleaning processes specifically designed to remove contaminants like glue from space-shuttle parts. In addition, spaceflight is also hostile to bar-code labels.

Another problem that has been encountered is that of compiling information about parts. At the beginning of the space-shuttle program, parts were tracked manually. As the flight rate increased, the amount of data collected was roughly equivalent to the amount of data collected in several large grocery stores each day. This situation created a backlog of paperwork that took as long as three months to catch up with the finished product.

Around this time, a Department of Defense study found that people made errors on one out of every 200 characters entered. For NASA, that meant, theoretically, that one out of every 10 part numbers entered into a data base was affected by a data-entry error. The direction was clear: To ensure the timely flight-worthiness of the space shuttle, it was becoming necessary to develop new techniques for marking parts without damaging them, and to develop an identification system, based on marks, as efficient as that of bar codes.

Because of the inherent limitations of bar codes for direct marking of parts in the aerospace industry, NASA sought a more suitable method of automated identification tracking. In September 1991, Marshall Space Flight Center established the Compressed Symbology Laboratory to investigate marks, roughly equivalent to bar codes, that could be applied directly to parts by use of permanent marking methods. The chosen general form for such marks was that of a two-dimensional matrix symbol that stores up to 100 times as much information as does a one-dimensional, linear bar code in the same area. The matrix symbol is a small square that resembles a checkerboard. The symbol is read by use of a charge-coupled-device (CCD) video camera.

Thirty marking methods were evaluated on more than 60 materials. Included were methods of computer-controlled direct marking by laser irradiation, dot peening, micro-sandblasting, and machine engraving; these methods worked well on metals. For marking such other materials as ceramics, mica, and graphite it was found necessary to apply permanent inks, precious metals, and ceramic-based coatings, sometimes in conjunction with engraving to penetrate coated surfaces.

Marking of textile products (including clothing, parachutes, tent materials, and other items) was upgraded by use of an automated-embroidery marking method. Gold was marked by depositing a thin liquid film of platinum. To facilitate the non-automated marking, new techniques of stenciling were tried. Some of these techniques were derived from a photographic transfer process, and others from computer-driven cutter/plotters. Finally, a process that closely resembles today's direct hot ink transfer was used in some applications to transfer patterns from film sheets to surfaces of parts.

By 1996, Marshall Space Flight Center researchers felt that many aspects of compressed symbology were ready for introduction into the commercial sector, even though the marking techniques developed to that point had not proven suitable for highly stressed NASA parts or could not provide the resolution needed for small parts. In August 1997, Marshall Technology Transfer formed an alliance with CiMatrix and its parent company, Robotic Vision Systems, Inc., (RVSI) to develop commercial applications for NASA's marking processes for the Data Matrix™, which is the CiMatrix patented version of the matrix symbol. The alliance also enabled two years of development of new marking methods that would satisfy NASA's requirements on stress-critical hardware.

The applications for the Data Matrix™ seem unlimited. Readable symbols have been applied on more than 80 different materials, including metals, plastics, glass, paper, fabric, ceramics, and others. Application processes have been tailored to materials, and some materials can be marked by use of multiple techniques.

Matrix symbols can be applied to aluminum by dot-peening, electrochemical etching, laser marking, or laser bonding; or by ink-jet, silk-screen, stencil, or film deposition. The symbols can be embroidered on cloth or stenciled onto rubber. There is a technique for marking almost any substance or item. Regardless of the technique used, the mark is permanent, is smaller than a bar code, and can be easily read by use of a CCD video camera.

Before compressed symbology was available, manufacturers of computer chips had no way of marking their products, and counterfeit chips flooded the market. The same is true of other small electronic parts. Automobile manufacturers can use compressed symbology to track each piece of an automobile, thereby narrowing the scope of, and simplifying, the recall process. The symbols have already begun appearing on items used every day. Because of their versatility, data-matrix symbols are being used to mark a wide variety of products, including such household items as jars of mustard, deodorant sticks, vitamin jars, and packages of photographic film. Data Matrix™ has now become the symbol of choice for direct marking of parts in the automotive, electronics, and aircraft industries.

But it does not stop there because NASA has part-identification needs that go beyond visible marks. Identification marks might be covered by paint, cork, foam, or a number of other coatings designed to protect parts. Six techniques for reading identification symbols under coatings, through containers, and within an assembly are in the patent process. NASA has begun soliciting partners to develop portable devices to implement these techniques.

Compressed symbology will have untold implications for industry as well as for NASA. New marking techniques within the ambit of compressed symbology, possibly ready this year, should open the door to marking stress-critical hardware.

*This work was performed by Fred Schramm of* **Marshall Space Flight Center**; *Donald L. Roxby of the OiMatrix Symbology Research Center (formerly of Rockwell); Willis L. Pavolini, Terry L. Higdon, and James D. Teed of Rockwell/Boeing; and Ward F. Davis and Robert Sant'anselmo of Veritec.*

*Refer to MFS-28960/61/28776/867/974/959/31015 volume and number of this* NASA Tech Briefs *issue; and the page number.*

*Additionally, Marshall is currently seeking partners for the commercialization of six techniques of reading identification symbols under coatings (patents pending). See Technology Opportunity Announcements at http://www.nasasolutions.com/tech_ops/techops.html. For further information, contact Amy Witsil at Research Triangle Institute, (919) 541-6923 or awitsil@rti.org.*

# Books and Reports

## Automated Planning and Scheduling for a Large Interferometer

A report discusses the potential application of artificial intelligence (AI) to planning, scheduling, and control of the optical configuration and other aspects of the operations of a large astronomical interferometer. Scientific demand and technical requirements necessitate streamlining and optimization of the operation of such an interferometer, but it is difficult and often impossible to achieve the streamlining and optimization manually. The report focuses on (1) the Keck interferometer, which will utilize light collected by two large astronomical telescopes and up to six smaller "outrigger" telescopes; and (2) the Automated Scheduling and Planning Environment (ASPEN) software, various aspects of which have been described in previous *NASA Tech Briefs* articles, as an example of AI planning and scheduling software. Using these examples, the report describes how AI high-level planning and scheduling software, in conjunction with low-level sequencing, can be used to solve large-interferometer configuration and control problems. Advantages of AI over manual methods are described: these include ability to consider more complex combinations of resources and constraints, to generate large command sequences rapidly, and to replan rapidly to respond to unforeseen events.

*This work was done by Andrew Booth, Gregg Rabideau, Leonard Reder, and Steve Chien of Caltech for* **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Automated Planning for Interferometer Configuration and Control," see TSP's [page 1].*

*This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-21179.*

# END

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